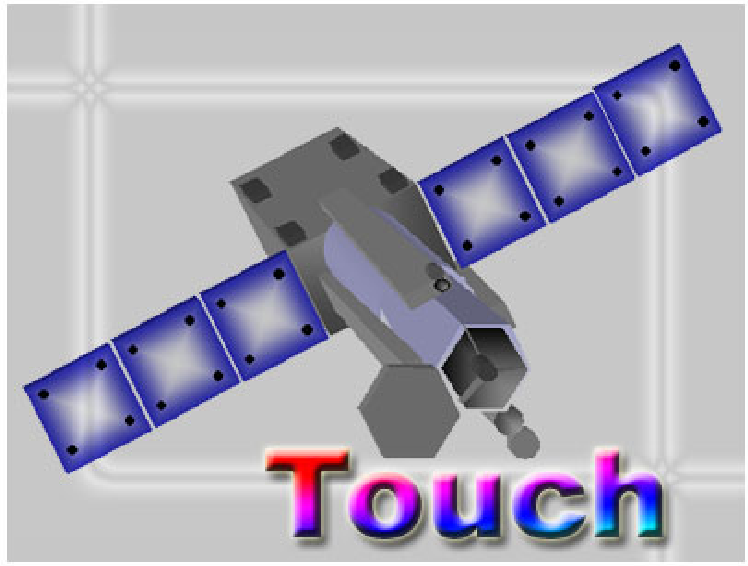


Touch the Sun

See the Sun in a new light

Solar-B Education and Public Outreach (EPO)

Solar-B is a multinational solar observatory satellite project headed by the Japanese Space Agency (ISAS), in partnership with the United States (NASA) and the United Kingdom (PPARC).

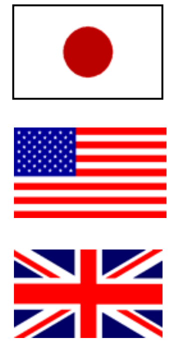
The Solar-B EPO program at Chabot Space & Science Center is funded by a grant from the Lockheed-Martin Solar and Astrophysics Lab (LMSAL) in Palo Alto, California.

The activities and materials in this package were developed for the *Touch the Sun* teacher-training workshop at Chabot Space & Science Center, 10000 Skyline Blvd., Oakland, California 94619.

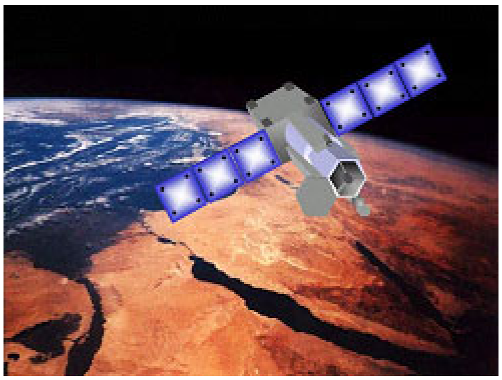
Contents

Touch the Sun

Solar B



Solar-B is a mission of Japan's Institute of Space and Astronautical Science, in partnership with the United States' National Aeronautics and Space Administration and the United Kingdom's Particle Physics and Astronomy Research Council.

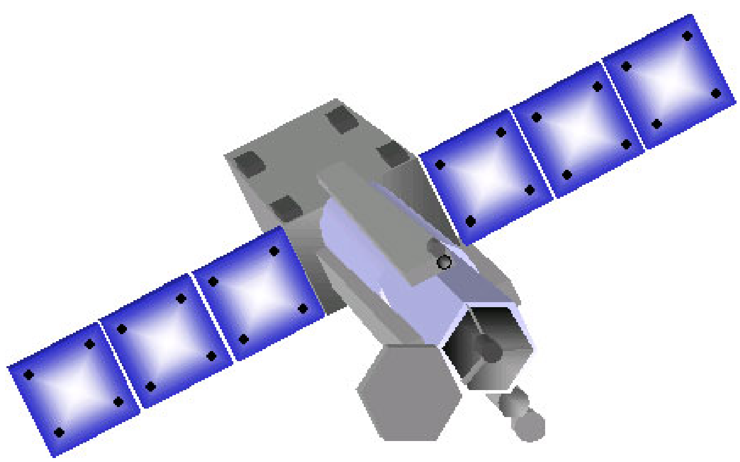


Human beings have observed the Sun for millennia, but in recent years technology has painted a much more complete picture, shedding light on the detailed workings of our star and causing us to ask an entirely new generation of questions. We have long known that the Sun's energy is essential to life on Earth. More recently we have discovered that changes in our Sun's behavior, driven by powerful magnetic activity, can affect the Earth's protective magnetic shield, climate, and our technological civilization.

Presently there exists a small fleet of satellite observatories focused on the Sun. In the last few years this intense, around-the-clock scrutiny by high-technology spacecraft operating in space, outside Earth's atmosphere, has greatly increased our understanding of the Sun, as well as its intimate connections to our planet, in particular to life on Earth.

As more knowledge of the Sun comes to light, new and sometimes unanticipated questions arise, begging more investigation. As technology advances, some of it spurred by earlier technological successes, so does our ability to investigate the Sun.

Solar-B is a next-generation solar observatory satellite, to be launched in the year 2005 from Kagoshima, Japan. With an array of instruments on board that will allow it to make coordinated observations in visible, ultraviolet, and X-ray light, yielding imagery, spectra, and polarization data, Solar-B will reveal facts about the Sun that are presently secrets, such as the cause of variability of solar energy output, the mechanisms that generate the Sun's powerful magnetic fields, and the cause of the intense heating of gases in the Sun's outer atmosphere, the corona.



Powerful impulsive phenomena, such as coronal mass ejections and solar flares, will also be studied.

Welcome

Welcome to Solar B *Touch the Sun!* This guide will lead you through an exploration of our Sun and the nature of its light. Choose a project, design and build a scientific instrument, collect and interpret data; you will be engaged in the scientific process, a powerful method for unlocking the secrets of nature.

Students may team up in groups of two to three. Each group will work together to create the best possible instrument and to collect the most accurate data. Each student may build and use their own instrument and collect and analyze their own data, but teamwork is highly encouraged.

A description of the *Touch the Sun* activities follows.

Sunspot Tracker

What Students Will Do

- With a simple lens system (binoculars or a small telescope), find and track sunspots and measure their movement across the face of the Sun.
- Sketch or trace the positions, sizes, and shapes of sunspots on the Sun's disk at different times over a week or two.
- Decide if the sunspots are moving and, if so, how fast.

What Students Will Learn

- Looking through a telescope at the Sun is dangerous and can cause permanent eye damage.
- The Sun can be observed SAFELY using a telescope as a projector.
- Sunspots can be thought of as magnetic "storms" on the Sun's visible surface.
- The Sun rotates in space just as the Earth does.
- Sunspots move with the Sun's surface as the Sun rotates in space.
- Sunspots can be viewed, recorded, and tracked, and from observations the speed of rotation of the Sun, at different solar latitudes, can be calculated.

Sundial

What Students Will Do

- Track the movements of the Sun through our sky.

- Build a simple sundial.
- Measure and record the length and direction of your sundial's shadow at different times of the day.
- Calculate the Sun's position in the sky (azimuth and altitude) from your measurements of the sundial's shadow.
- Graph your measurements of the Sun's position at different times of the day and estimate when true local noon occurred (rarely is it exactly 12:00 o'clock).

What Students Will Learn

- The Sun appears to move through our sky.
- The path that the Sun follows across the sky can be measured and predicted.
- The Sun's altitude when it reaches its highest point in the sky during the day depends on the time of year.
- The exact time of local noon (when the Sun reaches its highest point in the sky) can be estimated using the sundial.
- With careful measurement and some knowledge of geography, the time of the year can be estimated using a sundial.

Pinhole Camera

What Students Will Do

- Measure the angular size of the Sun and other objects.
- Build a simple camera from a cardboard tube, aluminum foil, graph paper, and a pin.
- Make observations of the Sun and record real-time data.
- Use the data to measure the diameter of the star in the center of our solar system.

What Students Will Learn

- An image of an object can be used to determine the object's size or the distance to the object (as long as one of these is already known).
- Light rays tend to travel in straight lines.
- Light rays from an object that pass through a small hole project an image of the object on the other side.

- An aperture is an opening through which light enters an optical device.
- The ability of the lens of the human eye to focus an image is aided by the eye’s pupil (the eye’s aperture), which acts as a pinhole camera.

Spectroscope

What Students Will Do

- Construct a simple grating spectroscope with a shoebox, paper, tape, cardboard, and a piece of plastic with a thousand tiny grooves etched on its surface (a “diffraction grating”).
- Learn of the electromagnetic spectrum, and of the spectra of various sources of light.
- Identify unknown elements with the spectroscope.

What Students Will Learn

- Light has wave-like properties
- The distance between successive wave “crests” in a light wave is the wavelength of the light
- The wavelength of light waves is very small, and is usually measured in nanometers
- 1 nanometer = 1 billionth of a meter
- Light waves normally travel through space in straight lines
- The direction that a light wave travels can be changed by the phenomena of reflection, diffraction, and refraction
- The amount that a light wave’s direction of travel is changed by diffraction or refraction depends on the wavelength of the light
- A spectrum is a range of values or properties: the electromagnetic spectrum is the range of all possible wavelengths of light; the visible spectrum is the range of all wavelengths of light that the human eye can see; the set of wavelengths of light present in a given source of light is called that source’s light spectrum
- With special instruments, such as a spectroscope, we can separate the different wavelengths of light and determine the light spectrum of any light source
- The wavelengths of light present in a light source can tell us what chemical elements emitted the light

Colorgraphs

What Students Will Do

- Explore the nature of color filters.
- Learn about filter spectral curves by observing the brightness of different colors of light through a filter and plotting the results.
- Use your understanding of the filter spectral curve to design your own filter by selectively combining two or more other filters.

What Students Will Learn

- Most sources of light that we see are made up of many different wavelengths (colors) of light
- In most cases, what the human eye and brain perceive as a specific color (for example, “red”) is actually a range of different light wavelengths.
- The human eye blends the different colors present in light; what we perceive is the blended result, not the individual colors present.
- Color filters are pieces of material (plastic, glass) that are transparent to some wavelengths of light and not so transparent (either translucent or opaque) to other wavelengths.
- The individual colors of light can be studied using color filters to block off certain colors.
- Color filters can be used to see certain colors without interference from colors we do not want to see.

Polarimeter

What Students Will Do

- Learn to pronounce words like “polarimeter,” “polarimetric,” and “polarimetry.” Also, learn what the words mean!
- When we think of light, usually the first characteristics that come to mind are color and brightness: what is the color of the light, and how bright is it? A not-well-known cousin of these properties is polarization.
- Use a polarizing filter to construct a polarimeter.
- Sleuth for sources of polarized light in the world around you.
- Make measurements of the direction and strength of polarization of light.
- Learn the ways that light becomes polarized, and what that can tell us about the object emitting the light.

What Students Will Learn

- Light is an electromagnetic *wave*: a wave of electric and magnetic fields.
- A light wave travels with its electric field *oscillating* within a geometric plane.
- Groups of light waves that travel in the same direction and whose electric fields oscillate in planes parallel to each other are called *plane-polarized.*
- Groups of light waves become polarized by different circumstances, including reflection from a smooth, shiny surface, being emitted by atoms that are inside a magnetic field, and by *stimulated emission* such as the light produced by lasers.
- Using instruments called *polarimeters* we can learn things about the object or environment that cause light to be polarized.

Shoebox Satellite

What Students Will Do

- Build from a shoebox, aluminum foil, paper, rubber bands, glue, tape, and other common materials a structure that will:
- Protect a cube of ice from melting under a hot lamp or direct sunlight.
- Protect an egg from fracture when dropped from a great height.
- Cost as little as possible to launch into space.

What Students Will Learn

- The environment of space is extremely hostile, to people and to machines.
- Engineering and building astronomical instruments (telescopes, for example) that are to be launched by rocket and operate in space requires special designs and special materials.
- The building and testing of models of space-bound telescopes can help us figure out the best way to design and build the real thing, before we send them into space or even before we build them.

Build It Right

Solar-B

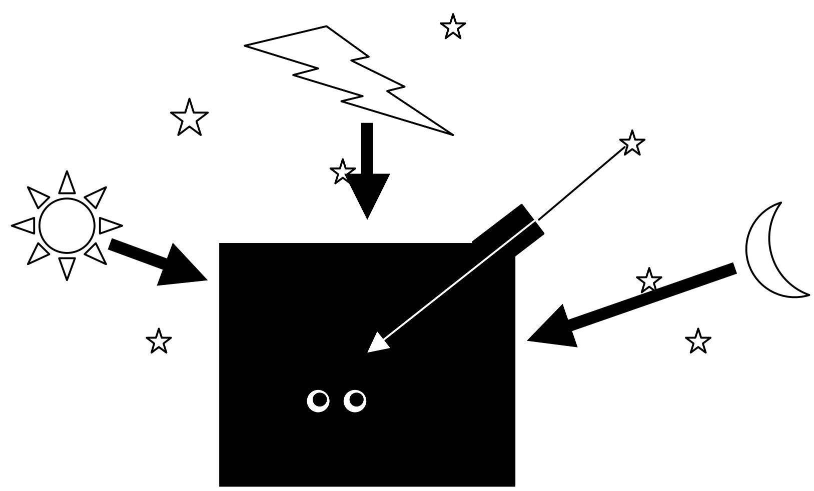
Satellite observatories like Solar B are truly wonders of science and technology. On one hand, they are complex machines, filled with delicate mirrors, sensitive electronics, computers, radio transceivers, and an extensive system of optics that must remain very accurately aligned.

On the other hand, the entire package must be stuffed inside a rocket's payload cone, hurled into orbit, ejected into the vacuum of space, subjected to extremes of hot and cold that reek havoc on machines, pelted with micrometeorites, hammered with solar radiation and cosmic rays, and finally expected to function continuously, without maintenance or the possibility of repair, for several years.

Spacecraft designers and builders must anticipate all of these conditions, and make all necessary tests of instrument parts and systems, before launch. There is no second chance.

Your Instrument

It is very important to think about the *design* of your instrument before you try to build it. Refer to the suggestions below as you are designing your instrument. They are suggestions of things to keep in mind as you proceed.



Minimize Unnecessary Light

Design your instrument so that **only the light from the object you are observing** reaches your instrument's *aperture* (the "eye" of your instrument). For some instruments this is not a big concern; the Sundial, for example.

For other instruments, if too much unwanted light gets into your eye it can be difficult or impossible to see the object's light. The Spectroscope and the Pinhole Camera are examples where you want to keep out all light except that of the object of interest.

Using a “light-tight” cardboard box is a great way to start since the box can also be used to mount color filters and polarizing filters and diffraction gratings and such.

Ease of Use / Pointing

Your instrument should be easy to use, easy to handle, and easy to point at a desired subject. This design consideration can make a big difference to data collection.

Ease of Making Measurements

Simply building an instrument and using it are only half of the fun. Making meaningful measurements and collecting data are essential.

Think about the type of data you will be collecting: exactly what will you be writing down or drawing or otherwise recording? Numbers? Sketches? Images? Graph entries? Once you understand exactly what type of data you will be collecting, you will understand better how to design your instrument.

Design for Abuse!

An instrument that falls apart in your hands as you attempt to use it is a waste of time ever to have built! Don’t make a flimsy instrument. Duct tape is much stronger than Scotch tape.

Classroom Considerations: Some Toe-holds and Springboards

General Reflections

The following questions can be used for whole group or small group discussions, and/or written assignments. It is especially important for students to have the time to talk and/or write after a “hands-on” activity. We don’t learn from our experiences so much as we learn from thinking about our experiences. These questions are structured to assist students with self-assessment.

Reflecting on Your Learning

As you think back on this activity, from design, to building, to testing:

- How did it go?
- Did you modify your original plan? If so, when and why?
- What went well? Why do you think so?
- What are some challenges or problems you faced? How did you solve them?
- How close are your data to the “ideal?” What might account for differences in the data collected? What are some things you/your group could do to modify your instrument in order to collect more accurate data?
- What are some things you learned (about engineering, testing, collaborating)?
- If you were to repeat the experiment(s), what would you do differently, and why?
- What questions do you now have?
- What have you learned about how scientists work together?

Assessment Idea for the Shoebox Satellite:

Following the testing of the Shoebox Satellite, “have each student prepare a report on one thing they propose in order to improve their team’s container and how they would test the effectiveness of their improvement” (National Standards, p.164).

Web Resources

Solar-B

Chabot Space & Science Center, "Solar-B Focal Plane," the Education/Public Outreach site for the Lockheed-Martin Solar-B Focal Plane Package project:
http://www.chabotspace.org/vsc/exhibits/solarb/default.asp

Lockheed-Martin Solar and Astrophysics Lab:

http://www.lmsal.com/

NASA Solar-B Information site:

http://science.nasa.gov/ssl/pad/solar/solar-b.stm

Solar

Daily Solar Images

Solar Data Analysis Center, NASA Goddard Space Flight Center:

http://umbra.nascom.nasa.gov/sdac.html

Latest SOHO Solar Images:

http://sohowww.nascom.nasa.gov/ >> *The Sun Now* link

Big Bear Solar Observatory:

http://www.bbso.njit.edu/cgi-bin/LatestImages

Mount Wilson Observatory:

http://www.astro.ucla.edu/~obs/intro.html

Mees Solar Observatory, University of Hawaii:

http://www.solar.ifa.hawaii.edu/Daily/mees_obs.html

Kitt Peak, National Solar Observatory:

http://www.nso.noao.edu/synoptic/synoptic.html

Sacramento Peak, National Solar Observatory:

http://www.sunspot.noao.edu/sunspot/latest_solar_images.html

Solar Learning Sites

Solar and Heliospheric Observatory (SOHO):

http://sohowww.nascom.nasa.gov/

Stanford Solar Center:

http://solar-center.stanford.edu/

Sun-Earth

Sun-Earth Connection Education Forum, NASA Goddard Space Flight Center:

http://sunearth.gsfc.nasa.gov/

SpaceWeather.com:

http://www.spaceweather.com/

NOAA Space Environment Center:

http://www.sec.noaa.gov/

Earth

United States Geologic Survey:

http://www.usgs.gov/

The Sun's Physical Characteristics

Mean Distance to the Sun—kilometers: 149,597,870

Mean Distance to the Sun—miles: 92,960,116

Diameter of the Sun—equatorial, kilometers: 1,392,530

Diameter of the Sun—equatorial, miles: 865,318

Perihelion Distance to Sun—kilometers: 146,605,913

Aphelion Distance to Sun—kilometers: 152,589,827

Sunspot Tracker

There's a little dark spot on the Sun today

Solar-B Education and Public Outreach (EPO)

Solar-B is a multinational solar observatory satellite project headed by the Japanese Space Agency (ISAS), in partnership with the United States (NASA) and the United Kingdom (PPARC).

The Solar-B EPO program at Chabot Space & Science Center is funded by a grant from the Lockheed-Martin Solar and Astrophysics Lab (LMSAL) in Palo Alto, California.

The activities and materials in this package were developed for the *Touch the Sun* teacher-training workshop at Chabot Space & Science Center, 10000 Skyline Blvd., Oakland, California 94619.

Sunspot Tracker

Nuts and Bolts

What Students Will Do

- Form a *real image* of the Sun large enough to reveal *sunspots*.
- Record the number and positions of sunspots several times throughout the week.
- Attempt to calculate the speed of the Sun's *rotation* by tracking sunspots over time.

Key Concepts

- Looking at the Sun with a telescope, or even with the naked eye, is dangerous. Permanent eye damage can result. Don't do it.
- A telescope or binoculars can project an image onto paper in the same way that a camera lens projects images onto sheets of photographic film, or CCD chips.
- Sunspots are temporary features on the Sun's surface that may last days, weeks, or even months.
- Sunspots can be several times larger than the Earth.
- The Sun rotates on its axis, but does so faster near its equator than near its poles; the Sun's equator completes one rotation in a shorter time than regions at higher latitudes.
- Sunspots can be used as visible reference points to track the motions of the Sun's surface.

Materials Needed

- A small telescope (preferred) or pair of binoculars (also see alternate, low-cost imaging method at the end of this unit)
- A tripod or similar mounting stand for the telescope or binoculars
- Multiple copies of a sunspot drawing template/data recording log (a sample is provided in this package)
- A pen or pencil (pencil preferred)
- A sunny day (actually, two or three)

Introduction

Description

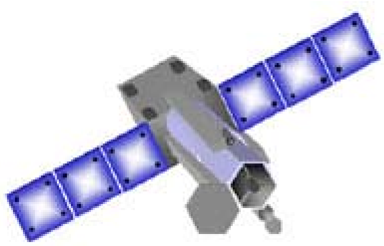
Sunspots can be thought of as “magnetic storms” on the Sun’s surface. They can be as large as the Earth, or even several times larger. They appear dark because the magnetic fields emerging from within the Sun at those places prevent the normal upward flow (convection) of hot gases rising from within the Sun.

Sunspots move along with the rest of the Sun’s surface as the Sun rotates in space. Since we can see them, sunspots can be used as reference markers that reveal the motion of the Sun’s surface.

The activity in this package is best conducted as a whole-class exercise, mainly because it may require the use of a telescope, and unless a student can provide their own, the teacher will conduct the activity with one telescope for the whole class.

You will need to record sunspot activity (positions and sizes) at least twice (preferably three or four times) over the course of at least two days.

Solar-B Connection



Sunspots are visible features on the Sun caused by the emergence of powerful magnetic fields from within the Sun. One of Solar-B’s prime subjects of study will be solar magnetic fields: how they are born, grow, and dissipate, as well as the driving source of energy behind them. Observing the motion of sunspots has been used for a very long time to clock the speed of the Sun’s rotation. Similar clocking of material motion will be performed by Solar-B scientists to measure the flow speeds and directions of materials on the Sun’s surface.

Setup

Overview

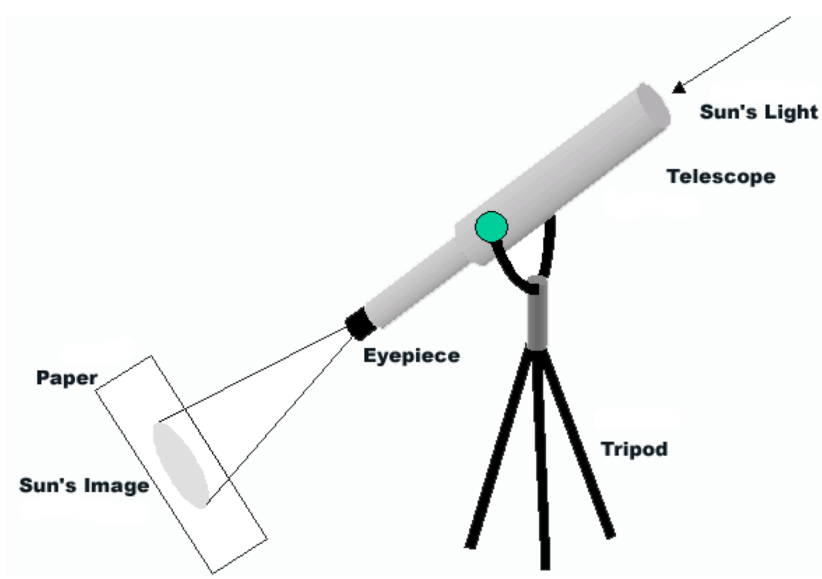
There are a number of methods for creating an image of the Sun, some expensive and others not. Binoculars or a small telescope, mounted on a tripod, are ideal. A pinhole projector can work, provided the distance from the pinhole aperture to the projection surface is large enough to produce a decent-sized image of the Sun's disk. **See the *Information for Teachers* section for suggestions on a low-cost alternative to telescopes.** The setup and observing instructions below assume the use of binoculars or a telescope.

Normally, you look at objects through a telescope by placing your eye to the eyepiece and viewing images directly. **However, you cannot do this when observing the Sun without harming your eye, possibly permanently. Never observe the Sun directly, either with an instrument or with your bare eyes.**

> Before you observe the Sun, repeat the following sentence one thousand times:
>
> ***I will not look directly at the Sun!***
>
> It is very important that you do not look directly at the Sun, not with a telescope, not with a camera, not with a pair of binoculars, not with your bare eyes!

Step by Step

To observe the Sun safely using a telescope or binoculars, point the instrument at the Sun as nearly as you can "blindly" (without looking into the instrument) and look for the Sun's bright light coming out of the eyepiece. You can hold your hand in front of the eyepiece, or place a piece of paper



there, in order to see the light. Once the Sun's light emerges from the instrument, place a flat piece of white paper in the light, holding it perpendicular to the direction that the telescope is pointing, as shown in the picture below.

The disk of light projected onto the paper is an image of the Sun, magnified by the telescope or binoculars. It may or may not be in focus, however. To focus the image, adjust the instrument's focus until you see a clear image of the Sun, with sharp, non-fuzzy edges. If there are any sunspots to see, then they too should come into focus. Note: If you are observing during a Solar Minimum of the 11-year solar cycle, sunspots may be scarce or not present at all; happy hunting!

Some suggestions:

- Construct a large cardboard shade to go at the front of the telescope to help shade the area where the Sun's image is being formed (the projection surface). A piece of cardboard with a hole cut out of it to fit around the telescope tube works very well.
- Construct a holder for the projection surface, one that will hold the surface and the drawing paper steady and allow you to sketch sunspots without moving the paper. Even something solid, sitting on the ground, against which a clipboard holding the drawing paper can be propped could be made to work.

Observe

Repeat your pledge:

I will not look directly at the Sun!

I do not wish to lose my eyesight!

Remember: If your eyeball is a grape, then a raisin is your eyeball after looking at the Sun….

Before You Observe

You will record a sketch of the positions and sizes of all the sunspots you observe, any interesting features of the sunspots, and the total number that you can count for that observation.

There are two ways that you can record this data. One is by looking at the projected image and sketching on a different piece of paper what you see.

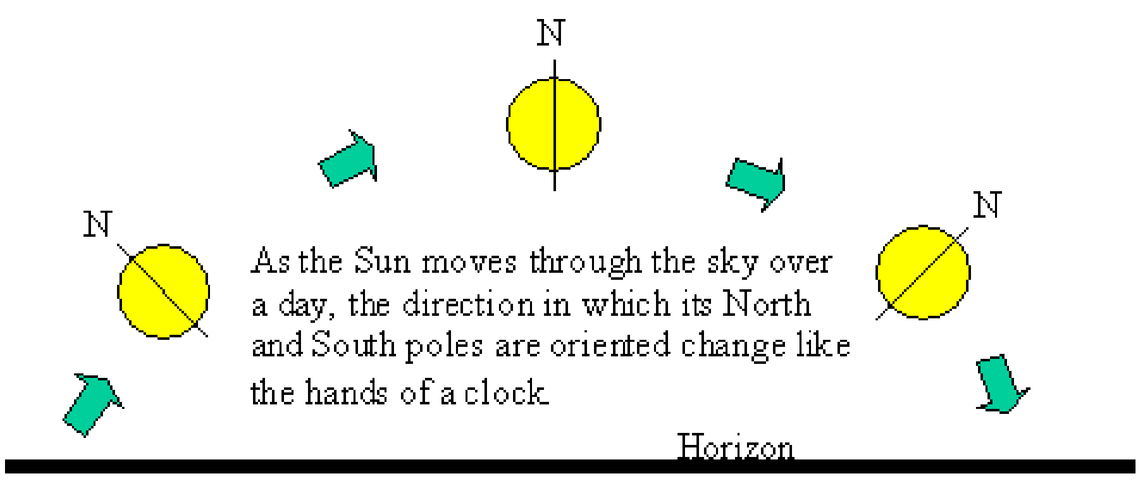
A better way is to place a piece of paper at the projection surface and trace the positions of sunspots you see directly onto the paper. To make the observing easier, you can prepare a batch of pre-drawn circle templates on small pieces of paper. Pre-drawing a circle of the same diameter as the Sun's image gives you a reference target for positioning the paper, and using small pieces of paper will make handling them easier.

There are some things to be aware of before you sketch or trace anything, however:

The Sun Moves: The Sun is constantly moving in the sky due to the Earth's rotation. Though we normally think of this motion as very slow, taking place over the course of an entire day, the image you are viewing through the telescope is magnified, so the Sun's motion will be noticeable even over a minute of time. If you have decided to trace the positions of sunspots directly, then to get an <u>accurate</u> map of sunspots for a given time you must sketch quickly, before the Sun's image has moved much. Or, if you see that the Sun and its spots have moved before you finish tracing, you can adjust the position of the paper you are tracing so that the sunspots that you have already sketched line up with the sunspots in the Sun's image.

Keep the sunspots you sketch aligned with the actual sunspots in the projected image.

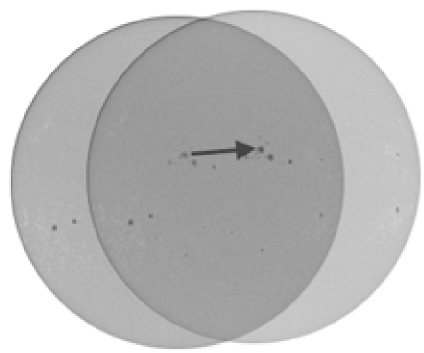
The Sky Turns: When recording sunspots over different days of the week (in order to track their motion over time) it is important that the *orientation of the Sun* be the same on each sketch. That is, the Sun's equator and north and south poles need to be oriented in the same direction on all of the sketches. Depending on the time of day, and thus the direction in which the



Sun can be found, the orientation of the Sun's own coordinate lines will change. From our point of view on the rotating Earth, the Sun's coordinate lines (North, South, East, West) will turn like the hands on an analog clock.

The equator and poles of the Sun (like those of Earth) are imaginary reference lines and points. On the Earth, if you know the shapes of the continents and oceans you can figure out which direction is North, which is South, and about where the equator is simply by looking at an image of the planet. The Sun not only has no continents or oceans, the features that it *does* show (like sunspots) change their positions and shapes constantly, like clouds on Earth—and like clouds, last only a short time before dissipating.

The simplest way to ensure that the Sun's image is oriented the same way in all of your sketches is to make your observations at the same time of day (approximately) each day, and place your tracing paper in the same orientation (with respect to the telescope) as well.



Another way to orient your sketches is by taking advantage of the Sun's apparent westward motion in the sky caused by the Earth's eastward rotation. You will see this slow, steady motion in the image of the Sun that you project.

You can mark the direction of motion on the paper by marking the position of a sunspot, waiting half a minute or so, and marking the position of that same sunspot again, and drawing an arrow from the first marking to the second, as illustrated in the picture to the right.

Step by Step

1. Set up your instrument until you achieve a focused image of the Sun.
2. Place a pre-drawn circle template sheet in front of the eyepiece at a distance such that the Sun's disk fits nicely in the circle.
3. Quickly sketch the positions of all sunspots you see. As the image moves, you may need to reposition the paper to keep up with it. It is important that whenever you record a sunspot, the Sun's image is lined up with the template and any spots you have already drawn.
4. Label, with a name or a number, each sunspot or sunspot group. If this is not your first observation, use the same labels for particular sunspots that you labeled in earlier observations.

5. Record, by the label you gave each sunspot or sunspot group, any features or characteristics that you find interesting or out of the ordinary.
6. Count the total number of sunspots in your completed sketch and record the number. In this case, you should count the sunspots in any groups as individual sunspots.
7. Repeat this observation procedure over the course of a week or so, every day if possible. **Sunspots or sunspot groups that you have labeled should keep the same label for all observations**.

Data Sheet

Date:	Time:	Observer:
Sketch your sunspot observation on a small piece of paper with a circular template and attach it in the box to the right. Make sure that you indicate the direction of image motion for later reference. Sunspot Count: ________________	*(attach your sunspot sketch/template here)*	

Sunspot Label	Description (large, dark, small, light, etc.)

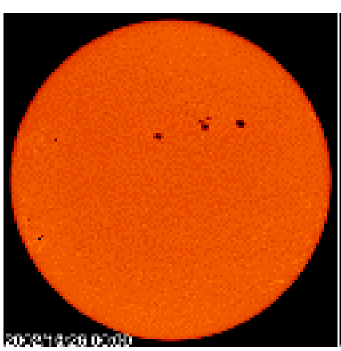
Analyze the Data

Step by Step

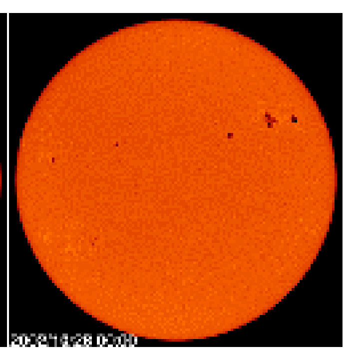
Here are detailed directions for analyzing your data. See also the worksheet on page 28.

From your recorded sketches of sunspots on at least two different days, you will attempt to measure the physical speed of a sunspot (in miles per hour or kilometers per hour) and use that speed to calculate the rotation period of the Sun (how long it takes for the Sun to rotate once on its axis).

1. Select two of your sketches that you believe are accurate, that were recorded at least a day apart and no more than about four days apart.
2. Select a single sunspot that is visible in both sketches (make sure it's the same sunspot!) that you will measure. NOTE: You are attempting to measure the physical speed of the sunspot by measuring how far it moves from side to side. The Sun is spherical in shape, so as it rotates sunspots that you see near the edge of the Sun's disk are actually moving toward you or away from you and may not appear to be moving as fast as sunspots closer to the middle of the Sun's image. To make as accurate a measurement as possible, select a sunspot located as close to the middle of the Sun's image as possible.
3. "Register" the two sketches: Place them together, one on top of the other, with the images of the Sun's disk lined up and rotated in the same orientation (with the drift directions you recorded aligned). This will form a two-page "flip book" that you can page back and forth to see any changes in the positions of the sunspots you sketched. You can combine the two images by carefully marking the sunspot positions of one sketch on the other sketch (perhaps using a different



Oct 26, 0:00 UT



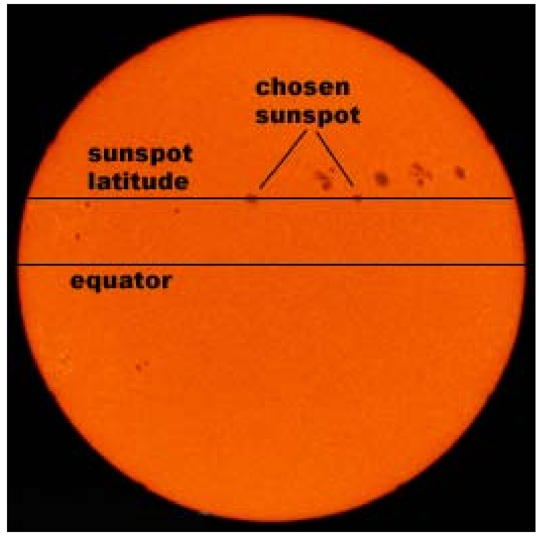
Oct 28, 0:00 UT

Combined Images

(sample images courtesy of SOHO/MDI)

color marker so that you do not confuse one day's sunspot positions with the other day's).

4. On the sketch where you combined both days' sunspot positions, use a ruler to draw a line through the two positions of the sunspot you have chosen. Extend this line so that it crosses the whole disk of the Sun's image. From Earth, we look at the Sun from the side (from above its equator), so this line represents the sunspot's latitude on the Sun, and the length of this line represents the diameter of that circle of latitude.



5. Now draw another line through the Sun's disk that is parallel to the sunspot's latitude and passes through the center of the Sun's disk. This line represents the Sun's equator. (Of course, if the line you drew through the two sunspot positions already passes through the center of the disk, then the sunspot was on the equator and you can skip this step.)
6. With a ruler, preferably in millimeters, measure: 1) the distance between the two sunspot positions; 2) the length of the sunspot's latitude line on the sketch; and 3) the length of the equatorial line. Note that the length of the sunspot's latitude line represents the diameter of that circle of latitude, and the length of the equatorial line represents the equatorial diameter of the Sun.
7. The fraction formed by the ratio of the two measurements is the same as for those dimensions on the real Sun. So the actual diameter of the circle of latitude (dcl) of the sunspot is

   $$\mathbf{dcl = (mdcl \ / \ mde) * D}$$

   where mdcl is the measured diameter of the circle of latitude of the sunspot, mde is the measured diameter of the equator, and D is the actual equatorial diameter of the Sun.
8. The fraction formed by the ratio of the distance moved by the sunspot and the diameter of its circle of latitude is also the same for the sketch and the real Sun. So, the distance that the sunspot moved (d) is

   $$\mathbf{d = (md / mdcl) * dcl}$$

where md is the measured distance the sunspot moved.

9. The physical speed the sunspot was moving (s) is the distance it moved (d) divided by the time it took to move (t), or

$$s = d / t$$

10. To use this result for speed to figure out the period of rotation of the Sun, you must first calculate how far the sunspot will move during one rotation of the Sun, which is the circumference of its circle of latitude. From the formula for the circumference of a circle, the circumference of the sunspot's circle of latitude is

$$c = PI * dcl$$

where PI = 3.1415926 and dcl is the diameter of the circle of latitude.

11. Once you have the speed of the sunspot (s) and the distance it must travel (c), you can calculate the time it takes (T):

$$T = c / s$$

This is your calculated period of rotation of the Sun.

Work Sheet

Diameter of Sun's disk measured on the sketch (mde):

____

Diameter of sunspot's circle of latitude measured on the sketch (mdcl):

____

Distance the sunspot moved measured on the sketch (md):

____

Actual diameter of the sunspot's circle of latitude (dcl = (mdcl / mde) * D, where D = 865,318 miles):

____

Actual distance the sunspot moved (d = (md / mdcl) * dcl):

____

Actual speed of the sunspot (s = d / t, where t is the time between measurements):

____

Circumference of the sunspot's circle of latitude (c = PI * dcl, where PI = 3.1415926):

____

Period of rotation of the Sun at the sunspot's latitude (T = c / s):

____

Lessons Learned / Questions / New Ideas

Now that you have experienced the process of setting up, using, and analyzing data from a simple solar imaging system, write down all of the things that you would do differently (if anything) if you were to build another.

1. What would you do to improve the setup of the telescope?
2. What would you do to improve the way in which you use the telescope and data sheet to collect data from the Sun?
3. How do you think any of these changes would improve the ease of use and accuracy of the data collected?
4. If you accomplished this activity with any different methods, what were they? Do you think your methods were better? Worse? Why?
5. What questions do you have?
6. What are some things that you now understand about the sun that you did not know before?

Information for Teachers

Our Sun is an enormous ball of *plasma* (hot, ionized gases, mostly hydrogen and helium) powered by the fusion of hydrogen into helium at its core. The gases of the Sun are so hot that most of the atoms present there are ionized—stripped of one or more of their electrons. Thus, the Sun is churning mass of positively charged atomic nuclei and negatively charged electrons.

Motions of electrical charge generate magnetic fields, as can be demonstrated by an electromagnet. The motion of electrical charge in the Sun, either by the convection of mass or thermal motion, generate magnetic fields there.

Powerful magnetic fields erupt from under the Sun's visible surface (the *photosphere*, or "sphere of light"). Where they pass through the photosphere they have the effect of cooling the region where they emerge, causing that region to appear darker than the surrounding solar surface. These cooler areas we see as sunspots, ephemeral islands of cooler gas locked up in magnetic fields that move along with the general rotational motion of the Sun's surface.

We can capture images of the Sun and its sunspots at different times and, by comparing two or more images, follow the motion of the spots, and thus the surface surrounding them.

Telescopes and magnified cameras can be used to capture these images. Images can be made on photographic film, CCD camera chips—or directly on a sheet of white paper, recorded by marking with pencil the locations of all spots seen.

To create an image of the Sun, a small telescope is required. The higher the magnification of the telescope, the larger an image of the Sun that can be produced.

It is very important NEVER to look through the telescope's eyepiece at the Sun, even when pointing the telescope to find the Sun's image. The best way to align the telescope so that the Sun's image emerges through the eyepiece is to set up the telescope on a tripod and roughly aim the scope at the Sun. You might get lucky and only have to move the scope around just a little bit before seeing the Sun's bright light streaming out of the eyepiece. Or, you may have to hunt around. **In either case, resist the urge to put your eye to the eyepiece to look for the Sun; you may damage your eye, possibly permanently**.

Once you find the Sun's image, place a white piece of paper under the eyepiece, perpendicular to the optical axis of the telescope (the direction that the light is traveling through it). Move the paper toward and away from the eyepiece until the Sun's disk fits in your record sheet's circular template.

Then, adjust the telescope's focus knob. When the edge of the Sun's image is sharp and clear, you're probably near best focus. Look for sunspots—dark spots that move around with the Sun's image (as opposed to pieces of dust in the telescope, which will remain fixed within the telescope's field of view). If you see any sunspots, you can further adjust the focus until they are as sharp as possible.

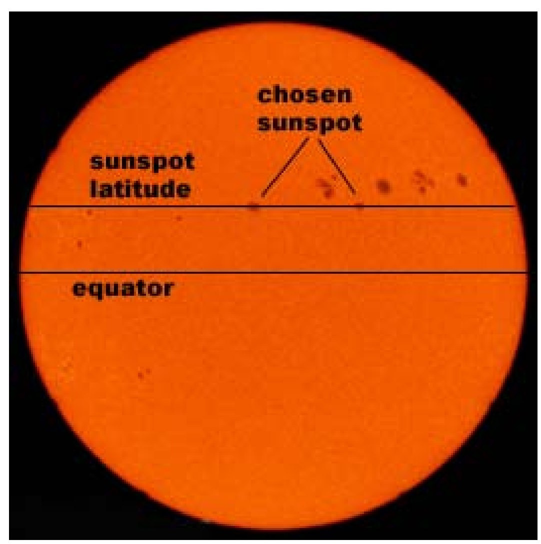
Now, carefully record the positions and sizes of all sunspots you see by marking them on the paper with a pencil.

Make observations one or two days apart, over the course of a week or so. From the set of images you have recorded, you can track the motion, and speed, of the sunspots, and thus of the Sun's surface.

Example of Calculating Sunspot Speed and Solar Rotation Period

The following example uses the combined images in the picture below (recorded Oct 26th at 0:00 UT and Oct 28th at 0:00 UT, respectively—UT is "Universal Time," which can be treated as Greenwich Mean Time), and the measurements are based on a printout of this page. Variable names are defined in the *Analyze Data: Step by Step* instructions and work sheet.

<u>Physical speed of sunspots</u>: The method described here assumes that you have chosen a sunspot that is as close to the center of the Sun's image as possible (so that the sunspot you observe is moving from side to side as much as possible, and not toward or away from us).



Draw the lines representing the sunspot's latitude and the Sun's equator (which is parallel to the sunspot's latitude and runs through the center of the circle). Measure with a ruler:

mdcl = 64 mm

mde = 67 mm

md = 14 mm

Calculate the actual diameter of the sunspot's circle of latitude:

$$dcl = (mdcl / mde) * D = (64 / 67) * 865{,}318 = 826{,}572 \text{ miles}$$

Calculate the actual distance moved by the sunspot:

$$d = (md / mdcl) * dcl = (14 / 64) * 826{,}572 = 180{,}813 \text{ miles}$$

Calculate the speed of the sunspot:

$$s = d / t = 180{,}813 / 48 \text{ hours} = 3{,}767 \text{ miles per hour}$$

Rotation Period of the Sun:

Calculate the circumference of the sunspot's circle of latitude:

$$c = PI * dcl = 3.1415926 * 826{,}572 = 2{,}596{,}752 \text{ miles}$$

Calculate the period of rotation of the Sun:

$$T = c / s = 2{,}596{,}752 / 3{,}767 = 689 \text{ hours} = 28.7 \text{ days}$$

Alternate Method: Determining Latitude of Sunspot

The diameter of the circle of latitude for a sunspot can be calculated directly from the latitude of the sunspot, by the equation

$$dcl = D * \cos (\text{latitude})$$

where D is the Sun's equatorial diameter.

You can measure the latitude of your sunspot by drawing a line from the center of the Sun's disk through a point on the circle's perimeter that meets the sunspot's latitude line. The angle that this line makes with the equator line is equal to the latitude of the sunspot.

Pinhole Projector: A Low-Cost Alternative to Telescopes

As described in the *Pinhole Camera* activity, you can form an image of the Sun by simply projecting a beam of its light through a tiny hole. The spot of light produced is an actual solar image, its size proportional to the distance between the pinhole and the projection surface. The longer that distance, the larger the image of the Sun.

The size of the pinhole affects two aspects of the image: focus and brightness. The smaller the pinhole, the more focused—but also the fainter—the image. It's an unfortunate tradeoff.

Building a pinhole camera of the style described in the *Pinhole Camera* activity that is long enough to produce an image of the Sun suitable for sunspot tracking is impractical. Here is a better way to build a pinhole camera projector with which you can track sunspots. Note: This design is modeled after the Exploratorium "Snacks" activity, "Reflections of a Star."

Materials Needed:

- A plastic soda-bottle.
- A piece of 4x4 wood with a "v" groove cut down one face (the length of the 4x4 is roughly equal to the length of the soda bottle).
- A small mirror, a centimeter or two in diameter (this mirror serves as the pinhole projector's aperture, but instead of being a hole through which sunlight can pass, it forms a "hole" from which sunlight is reflected; this setup allows the beam of light to be reflected in a desired direction).
- A darkened area into which a beam of sunlight can be reflected.

Construction Procedure:

- Glue the small mirror to the outside surface of the soda bottle, about halfway between the top and bottom of the bottle.
- Fill the soda bottle with water (the water serves as ballast only; its optical properties are not utilized!)
- Set the 4x4 on its side with the v-shaped groove facing upward.
- Lay the soda bottle on its side in the v-notch groove of the 4x4.

Operation Procedure:

Set the entire assembly somewhere in sunlight with the mirror facing in the general direction of the Sun. The small mirror will reflect a beam of light.

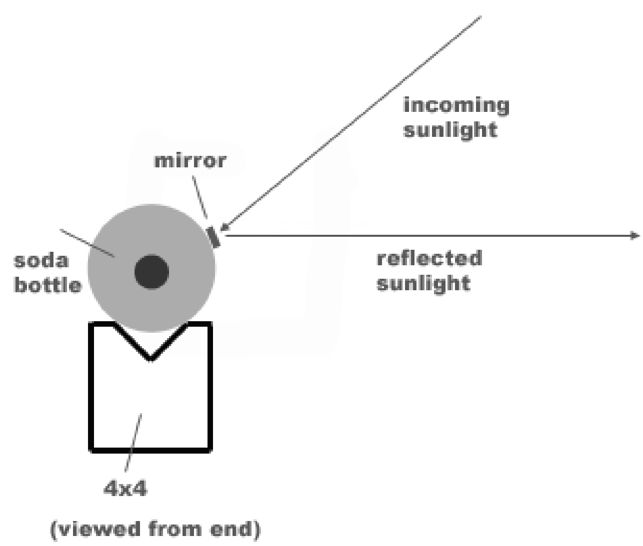
You can rotate the 4x4 on the horizontal plane and rotate the soda bottle in its groove holder in the vertical plane to direct the beam of sunlight in a desired direction.

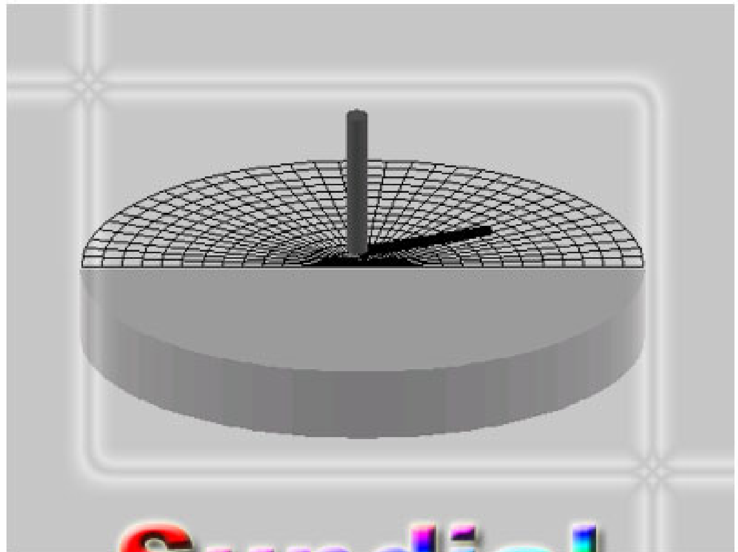
If you have wisely chosen a location to operate this pinhole projector, you may now direct the reflected beam of sunlight into an area that is shaded and not bright with ambient light. Ideally, if you can direct the beam into a building, through a door or window, and darken the interior as much as possible, then seeing the projected solar image will be much easier.

You can easily experiment with different projection distances to see what works best for you, depending on your specific situation. A projection distance of 10 or 20 meters is not out of the question!

The disk of light projected by this pinhole projector can be made large enough (with a great enough projection distance) and sharp enough (by using a small enough mirror, or a mirror masked by a piece of paper with an appropriately sized hole cut out of it) to make useful observations of sunspots. You may have to sketch your image by holding a piece of paper up against a wall, but you will get your data!

Right: View of the soda bottle pinhole projector, seen on-end





Sundial

When is high noon, and how high is it?

Solar-B Education and Public Outreach (EPO)

Solar-B is a multinational solar observatory satellite project headed by the Japanese Space Agency (ISAS), in partnership with the United States (NASA) and the United Kingdom (PPARC).

The Solar-B EPO program at Chabot Space & Science Center is funded by a grant from the Lockheed-Martin Solar and Astrophysics Lab (LMSAL) in Palo Alto, California.

The activities and materials in this package were developed for the *Touch the Sun* teacher-training workshop at Chabot Space & Science Center, 10000 Skyline Blvd., Oakland, California 94619.

Sundial

Nuts and Bolts

What Students Will Do

- Build a "solar powered" Sun-position measuring device.
- Measure the length and direction of a shadow cast by a stick in sunlight over the course of the day.
- From your measurements, calculate the Sun's azimuth and altitude.
- Graph the azimuth and altitude.
- Estimate the time of true local noon at your location.
- Estimate the Sun's *altitude* at true local noon.

Key Concepts

- The Sun appears to move through the sky throughout the day.
- The Sun's motion through the sky on a day-to-day basis is caused by the Earth's rotation on its axis.
- The position in the sky of the Sun can be measured from the length and directions of shadows cast by stationary objects.
- The motion in the sky of the Sun can be determined by making multiple position measurements.
- True Local Noon is the time when the Sun reaches its highest altitude for a given day, or, alternately, the time when the Sun is directly south (for Northern Hemisphere observers).
- By measuring and graphing the altitude of the Sun in the sky at different times during the day, the time of true local noon can be estimated.

Materials Needed

- A flat base (e.g., wood, cardboard, foam-core)
- A stick (the gnomon; e.g., a dowel, a toothpick)
- Protractor, drawing compass
- Glue, plain paper, and pen
- Graph paper (for graphing data)

- A magnetic compass and a bubble level (optional)

Introduction

Description

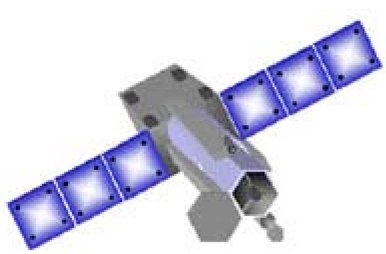
The sundial is an ancient device used to tell the time of day by measuring the position of the Sun's shadow. As the Earth spins on its axis, the Sun's position in the sky changes. At dawn it appears to rise from the East, climbs to its highest point at *true local noon* (when it crosses the *meridian* of the observer), and falls to the western horizon, departing the skies until the next dawn. An observer's meridian is an imaginary line drawn on the sky, running north to south and passing through the observer's *zenith*—the point directly overhead. In the Northern Hemisphere, the Sun crosses the meridian when it is directly south of the observer.

This apparent motion of the Sun causes shadows cast by objects attached to the Earth to move. The sundial makes use of this shadow motion. The simplest sundial is made up of something that creates a shadow, called a *gnomon* (pronounced nō' mŏn), and something that the shadow falls upon for measurement--the *dial*.

The sundial is most famous as a device for measuring time. Depending on the time of day (and so the position of the Sun), the direction and length of the gnomon's shadow change. The dial can be marked so that the direction of the shadow points to the time of day.

This project, however, does not make use of the sundial's time-telling ability. You will design, construct, and use a sundial to track the motion of the Sun through a day, or part of a day. You will make measurements of the direction and length of the gnomon's shadow that allow you to calculate the Sun's *altitude* and *azimuth*. From this data, you will be able to estimate the time of true local noon.

Solar-B Connection



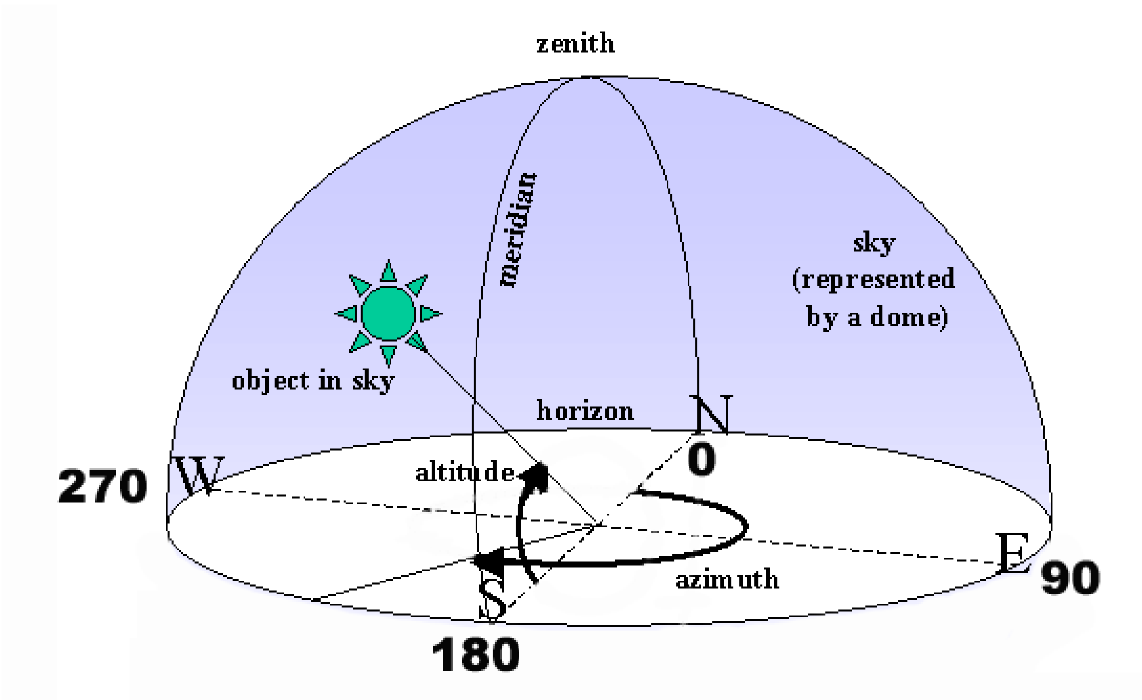
Though Solar-B will not have a sundial on board ☺, the nature of the Sun's motion through the sky during the day and throughout the year is one of the most well-known and perceivable Sun-Earth connections. The altitude of the Sun in the sky has a direct effect on the strength of sunlight reaching the ground, due both to the amount of atmosphere the light must pass through and the surface area on the Earth that it is spread across.

We have all experienced how much weaker the Sun's rays are near sunset than they are at high noon: too bright to look at in mid-day, you can almost comfortably look at the Sun near sunrise and sunset (though looking directly at the Sun is not recommended even then).

The changing maximum altitude of the Sun over the course of the year is what causes the seasons. In winter, the Sun's maximum altitude is not as great as in summer, and the overall effect of solar heating over the course of the day is weaker. Thus winter days are colder than summer days, in general.

Azimuth and Altitude

Azimuth and altitude are two angles that pinpoint the location of an object in the sky, relative to an observer and the observer's horizon.



Azimuth and Altitude of an object in the sky relative to the observer (at the center).

Azimuth: The angle measured horizontally from the geographic north to the point on the horizon directly under the object. North is at an azimuth of 0 degrees, East at 90 degrees, South at 180 degrees, and West at 270 degrees.

Altitude: The angle measured from the point on the horizon below an object directly upward to the object. Objects at the horizon have an altitude of 0 degrees, while objects directly overhead have an altitude of 90 degrees.

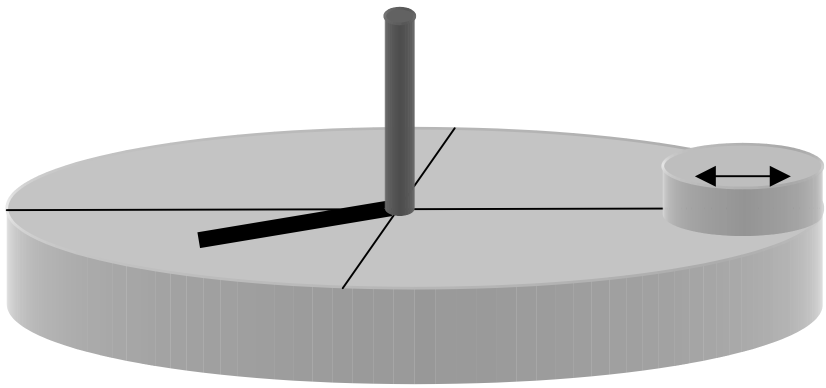
The direction that an object's shadow points is exactly 180 degrees (in the opposite direction) of the light source casting the shadow. So the Sun's azimuth is always 180 degrees away from the direction in azimuth that an object's shadow points.

The altitude of the Sun can be figured by comparing the length of a shadow and the height of the object casting the shadow.

Build It

Overview

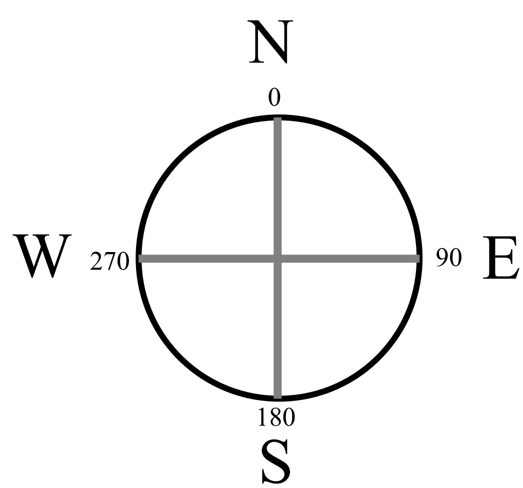
There are many ways to make a device that measures the Sun's position. A very simple device is one that creates a shadow whose *length* and *direction* can be used to determine the Sun's position. In either case, to determine azimuth you must be able to align your device with *geographic north*, so that *zero degrees* on your azimuth dial points to geographical north.



This picture shows the basic idea for the vertical stick version of a sundial. The base of the sundial should be something that you can set down on a flat, horizontal surface (a table, the ground, the top of a wall). It should also be something in which you can mount the stick firmly and securely. A piece of wood is great, but even sturdy cardboard can work. The base does not have to be circular. A square or rectangle will also work.

Step by Step

Draw the azimuth dial on the base:



1. Draw two perpendicular lines that cross each other at the center of the base (note: these lines must intersect at the point where the gnomon will be mounted). These lines represent north, south, east, and west.
2. Draw a circle centered where the two perpendicular lines cross. You can use a drawing compass or a protractor to

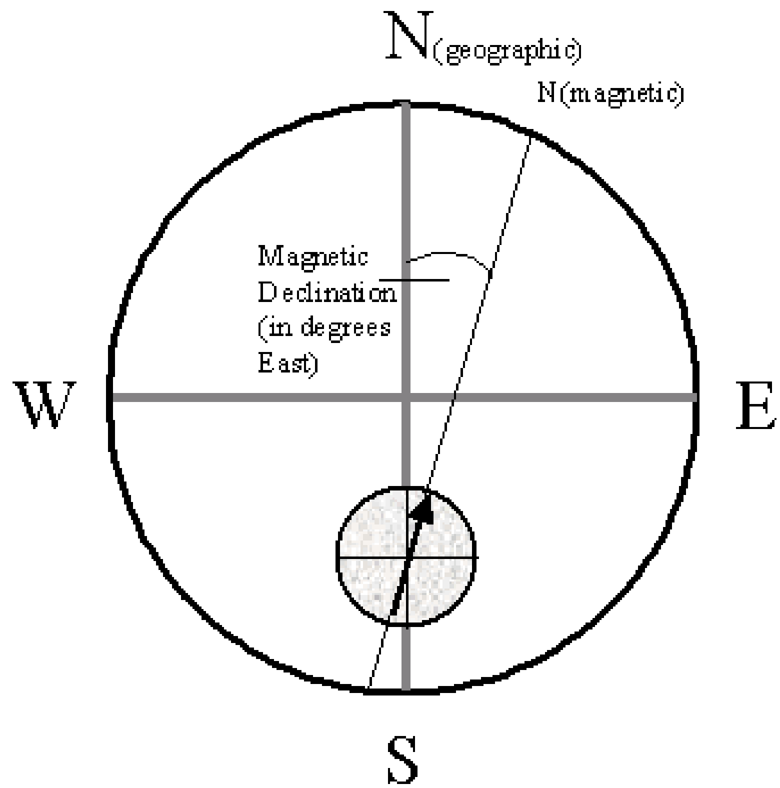
do this.

3. Use a protractor to mark off the circle in degrees (every 5 or 10 degrees is okay), starting with 0 degrees at the north (N) position and counting up in the clockwise direction with 90 degrees at east (E), 180 degrees at south (S), and 270 degrees at west (W). *Question: Do you need to mark off the entire circle, or can you get away with marking only part of the circle? If so, which part?*
4. Mount the gnomon (the vertical stick) at the center of the dial circle**. It is very important that the stick is mounted <u>perpendicular</u> to the base** so that when the base is sitting on a flat, <u>horizontal</u> surface, the stick is **<u>vertical</u>**.
5. Last, mount a magnetic compass on the base.

   The compass will help you align the azimuth dial with the true geographic directions: you want north on your dial to point to geographic north on the horizon.

   The idea is to rotate the base of the instrument until the north-south line on the dial lines up with the compass needle.

   This will align the base dial with *magnetic north* – but, of course, you want to align your instrument with true *geographic north*. To use the compass to align the dial with geographic north, draw a line somewhere on your dial that makes an angle with the N-S line by an amount corresponding to the *magnetic declination* (see the definition of magnetic declination at the end of this section in *Information for*

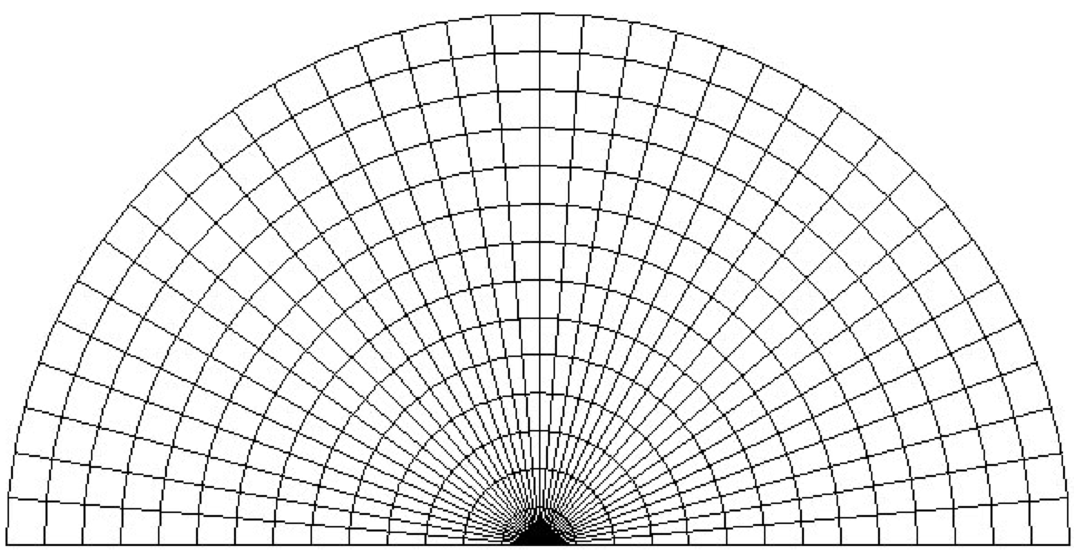


In the picture above, suppose the dial's north is aligned with true geographic north. The needle, of course, is pointing to magnetic north. The angle between the geographic N-S line and the compass needle is then equal to the magnetic declination for the location on Earth where the sundial is located. When you align the compass needle with the diagonal line (the magnetic north line), the main dial's directions automatically line up with true geographic directions.

Teachers) for your location on Earth. When you align the base, line up the compass needle with the magnetic line. For example, the magnetic declination of the San Francisco Bay Area is 17 degrees East, so if you are observing from this location you would draw your magnetic north-south line at an angle of 17 degrees to the east of north (clockwise).

6. An option that you might want to include on your sundial is a circular bubble level. If you attach the bubble level to the flat base of the dial, then you can be sure that the base is horizontal when you make a measurement.

Below is an example of a pattern for the markings on a sundial. In this example each angular unit, for measuring gnomon shadow azimuth, is 5 degrees. The length of the radial units, used to measure the length of the gnomon shadow, may vary depending on the printer or photocopier used to print this page, so do not assume the spacing! It would be best for you to measure and draw you own dial.



Observe

Your sundial has been designed to measure the position of the Sun in the sky. Before you observe the Sun with it, repeat the following sentence one thousand times:

I will not look directly at the Sun!

It is very important that you do not look directly at the Sun, not with a telescope, not with a camera, not with a pair of binoculars, not with anything. Since you only have to observe a shadow cast by the Sun, you should not have to look in the direction of the Sun anyway.

Make your measurements of gnomon height and shadow length in millimeters.

When you make an observation with your sundial, you will first align the dial with true geographic north. Then, you will measure and record on the data sheet the direction (azimuth, in degrees) and length (in millimeters) of the gnomon's shadow. Also be sure to record the time of each measurement.

Make measurements at several different times during the day. The more often you make measurements, the better. One of your goals is to find out the time of true local noon, when the Sun is at its highest point in the sky, so you need to make measurements before and after true local noon.

If possible, once you set up your instrument and align it with geographic north, do not move it. If you cannot leave it in place, then each time you set up the sundial and make measurements, make sure that it is aligned with north and resting on a flat, horizontal surface.

Before you make any measurements, make sure that you fill in the information about date, time zone, whether Daylight Savings Time (DST) is in effect, your name, your latitude and longitude, your "magnetic declination," and the height of your sundial's gnomon (in millimeters).

Step by Step

1. Set your instrument on a flat horizontal surface. To make measurements as accurately as possible, your instrument base should be as close to horizontal (and your gnomon as close to vertical) as possible.

2. Align the sundial's base so that zero on your azimuth dial points to geographic north (either using the magnetic compass method or another means).
3. Without moving your instrument, measure the gnomon shadow's direction and length. Record your measurements on the data sheet.
4. Repeat the measurements at different times of the day, as often as possible. Try to make some measurements before and after the time of true local noon.

Remember, true local noon is the time when the Sun is directly south of you—what azimuth is this? What would be the azimuth of the shadow? True local noon is also the time when the Sun is at its highest altitude—how would you tell this from the length of the shadow?

Data Sheet

Date	**Time Zone**	**DST: Yes /No**	**Observer Name**	
Latitude	**Longitude**	**Magnetic Declination**	**Gnomon Height**	
Time	Shadow Length (measure)	Altitude of Sun (calculate)	Azimuth of Shadow (measure)	Azimuth of Sun (calculate)

After graphing and analyzing the data (see following pages) summarize your results here:

The time of true local noon occurred at: ☐

The altitude of the Sun at true local noon was: ☐

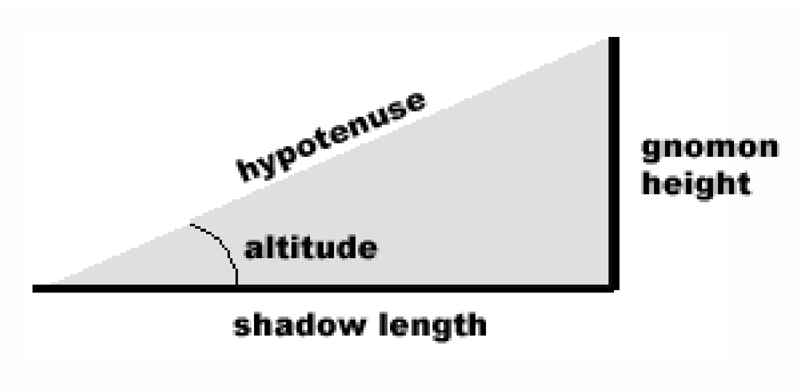
Analyze the Data

Calculate the Sun's Azimuth and Altitude

To complete your data log sheet, you must take your measurements of the gnomon shadow's direction and length and calculate the Sun's azimuth and altitude from them.

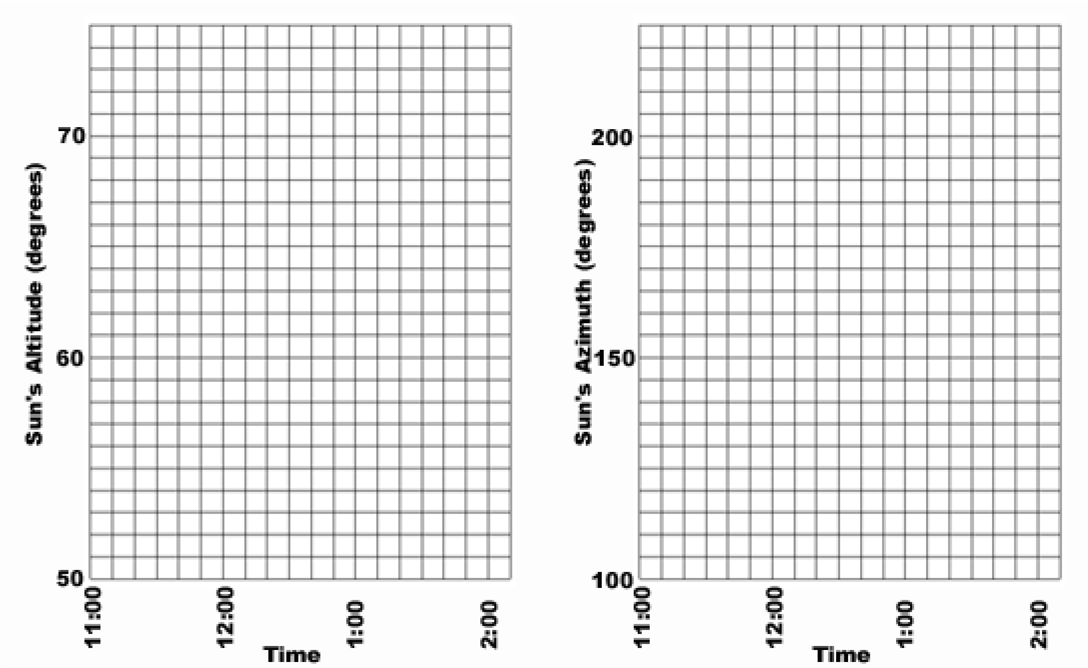
To calculate the Sun's azimuth, add or subtract* 180 degrees to/from the shadow's azimuth (*whichever operation gives a result between 0 degrees and 360 degrees).

To calculate the Sun's altitude, you can either use trigonometry (as described in the *Information for Teachers* at the end of this activity) or you can draw a right triangle on graph paper whose vertical leg is the length of the gnomon's height and whose horizontal leg is the length of the gnomon's shadow (recall that the gnomon is supposed to be perpendicular to the dial's base, and so the gnomon's shadow should be perpendicular to the gnomon as well; why is this so?). Draw the right triangle's hypotenuse from the top of the gnomon to the tip of the shadow. The angle that the shadow makes with the hypotenuse is the Sun's altitude, which you can now measure with a protractor.



Graph Your Calculations

Create two different graphs from your calculations. In one, plot the Sun's altitude versus time, and in the other plot the Sun's azimuth versus time. In each graph, draw a smooth curve or a straight line that best fits your plotted data points. (Do not simply connect the dots; try to "fit" a curve or line to the data points that is an average of the points.) Examples layout for the two graphs are given below.



Examples of Data Graphs: Altitude vs Time and Azimuth vs Time

Estimate True Local Noon

There are two ways to determine the time of true local noon from your graphs. One is to read from the **azimuth graph** the time when the Sun's azimuth was 180 degrees, directly south (or 0 degrees, directly north, if you are in the Southern Hemisphere). The other is to read from the **altitude graph** the time when the Sun reached its highest altitude.

Just for fun, find true local noon both ways and write down the times here:

Local Noon from Azimuth graph:

Local Noon from Altitude graph:

It is up to you to decide which time you want to call true local noon (or you might want to average the two numbers).

Follow-up questions:

1. By how much time, if any, did your estimated true local noon differ from noon according to a clock?

2. If Daylight Savings Time (DST) was in effect when you made your measurements, how did this affect your measurement of true local noon? (In other words, what would be the Standard Time for true local noon if DST were not in effect?)

Estimate the Sun's Altitude at True Local Noon

What was the Sun's altitude at true local noon?

Follow-up questions:

1. How did your answer compare to the answers from others in your class?

Lessons Learned / Questions / New Ideas

Now that you have experienced the process of building, using, and analyzing data from a Sun-position-tracking sundial, write down all of the things that you would do differently (if anything) if you were to build another.

1. What would you do to improve the design of your sundial (its size, dimensions, measurement surface)?
2. What would you do to improve the construction of your sundial (the materials used, the methods of attaching everything together)?
3. What would you do to improve the way in which you use the sundial to collect data from the Sun?
4. How do you think any of these changes would improve the ease of use and accuracy of the data collected?
5. What do you now understand about the Sun that you did not understand before?
6. What questions do you have?
7. In what other ways might you track the movement of the Sun in a systematic way?
8. In what other ways might your sundial be used? Can you re-design it to use it as a clock?

As a class:

1. Compare all of your results for <u>true local noon</u> and the Sun's <u>altitude</u> at that time.
2. Discuss why the results may be different.
3. Brainstorm a list of all the possible sources of error in your measurements and calculations that might account for the differences in results.

Additional Activities

Pinpoint Your Location on Earth!

You can use your measurements of the Sun's position in the sky to figure out where you are on Earth: your latitude and longitude. This activity assumes that you are at least somewhat familiar with the Earth's geographic coordinate system, the relationship between Greenwich Mean Time and your local zone time, and the seasonal change of the Sun's noon-time position in the sky. You will use your estimates of the time of true local noon and the altitude of the Sun at true local noon.

Pinpoint Your Latitude

Discussion: Because the Earth is tilted on its axis of rotation by 23.5 degrees, as the Earth revolves around the Sun the latitude at which the Sun is directly overhead changes day to day. At Summer Solstice in the Northern Hemisphere, the Sun is directly over the latitude of 23.5 degrees north. At Winter Solstice, the Sun is directly over the latitude of 23.5 degrees south. At all other times of the year the Sun is directly overhead at latitudes between these extremes. At either Vernal or Autumnal Equinox, the Sun is directly overhead at the Equator.

To calculate your latitude from the Sun's maximum altitude for a given day, you need to know the latitude where the Sun is directly overhead for that day. If you took your measurements on or near one of the Solstices (within two or three days of it) or on an Equinox, you may use the numbers provided above (23.5 for Summer Solstice, -23.5 for Winter Solstice, 0 for the Equinoxes; notice that a southern latitude is expressed as a negative number). For any other time of the year, you will have to determine the "sub-solar latitude" (the latitude at which the Sun is directly overhead) by another means. A formula that <u>approximates</u> the sub-solar latitude is:

$$\mathbf{23.5 * \sin ((DN - 80) * 360 / 365)}$$

where DN is the "day number" of the year—the number of days since the beginning of the current year. Note: If the value of (DN – 80) is a negative number, then add 365 to the result. Note: The value of 80 is subtracted from the day number since the Vernal Equinox, March 21^{st}, has a day number of 80 (on non-leap-years); this makes the sin term zero on Vernal Equinox and approximately zero on Autumnal Equinox, when the subsolar latitude is at the equator, or zero degrees.

Note: Another way to determine the sub-solar latitude is to read it from a graph called the *Analemma*. There is an Analemma at the end of this activity in the *Information for Teachers* section.

To calculate your latitude in the Northern Hemisphere:

$$\text{latitude} = 90 - \text{altitude} + \text{subSolarLatitude}$$

For example, if the sub-solar latitude is 23.5 degrees (as it would be at Summer Solstice in the Northern Hemisphere), the equation would read:

$$\textbf{latitude} = \textbf{90} - \textbf{altitude} + \textbf{23.5}$$

where the altitude is the value you estimated for the Sun at true local noon.

Pinpoint Your Longitude

Discussion: Your longitude, the number of degrees east or west of the Prime Meridian (the meridian of Greenwich, England), can be determined from your estimate of true local noon at your location expressed in *Greenwich Mean Time* (GMT). Imagine the stationary Sun in relation to the rotating surface of the Earth. At any given time, the Sun is at true local noon for some longitude on Earth. The exact longitude changes constantly as the Earth spins under the Sun.

The Sun passes through true local noon at Greenwich, England, at 12:00 GMT (noon in Greenwich—and because Greenwich is located on the Prime Meridian, true local noon and standard (zone) noon occur at the same time). Now, because the Earth rotates toward the east at a rate of 15 degrees of longitude per hour (360 degrees divided by 24 hours), one hour after 12:00 GMT the Sun will pass through true local noon at a longitude 15 degrees west of Greenwich. Two hours after 12:00 GMT it will be true local noon at a longitude of 30 degrees west of Greenwich, and so on.

Put another way, if you know that the Sun passed through true local noon for your location two hours past 12:00 GMT (in other words, 14:00 GMT, on the 24-hour clock), then you know that you are:

$$\textbf{2 hours * 15 degrees/hour = 30 degrees}$$

westward of Greenwich—in other words, you have a longitude of 30 degrees west.

The following equation can be used to calculate your longitude:

$$\text{Longitude} = (\text{GMT} - 12 \text{ hours}) * 360 / 24$$

where GMT is the Greenwich Mean Time that true local noon occurred at your location, which you estimated from your Sundial measurements. If you recorded the time in hours and minutes, before you use this equation you must first convert the GMT to decimal form. To do this, divide the minutes of time by 60 and add this result to the hours. For example, a GMT of 9:37 = 9 + 37/60 = 9.62 in decimal form.

If the answer you get is a negative number, then the longitude is east of Greenwich. If the answer is positive, then the longitude is west of Greenwich.

To convert your true local noon to GMT, do the following:

1. If Daylight Savings Time is in effect, first subtract one hour from your estimated true local noon.
2. Next, add or subtract the appropriate number of whole hours based on the standard time zone you are in. For example, the Pacific Standard Time Zone (8 zones west of Greenwich) is 8 hours earlier than GMT, so one would convert a PST zone time to GMT by adding 8 hours to the local time (PST is 8 hours earlier than GMT; GMT is 8 hours later than PST). The standard time zone that is 5 zones east of Greenwich is 5 hours later than GMT, so people in this zone would subtract 5 hours from their local time to find out what time it is in Greenwich.
3. If your result is less than 0 or greater than 23, you must add or subtract 24 hours to correct for the fact that there has been a crossover to a different day. For example, if the calculated GMT is 26:00, then subtract 24 hours to put the result within the range of 0 to 23 hours, in this case 26:00 minus 24 hours gives 2:00. If the result is, say, –7:00, then add 24 hours to get 17:00.

Activity Summary

Latitude and Longitude Worksheet

Latitude	
Date of Measurements:	
Altitude of Sun at True Local Noon:	
Sub-solar Latitude:	
Your Calculated Latitude:	
Your Actual Latitude (look it up):	

Longitude	
Date of Measurements:	
True Local Noon[1]:	
DST Correction[2]:	
Greenwich Mean Time (GMT)[3]:	
Your Calculated Longitude:	
Your Actual Longitude (look it up):	

1: This is the true local noon that you have calculated.

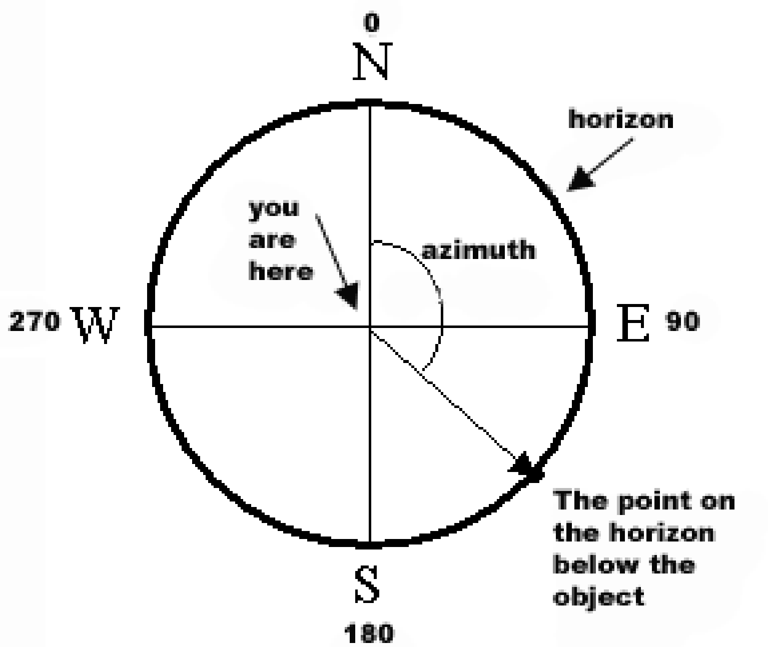
2: For the DST correction, subtract 1 hour from your true local noon IF AND ONLY IF your true local noon is in Daylight Savings Time.

3: To get the GMT add, or subtract, the number of hours your local standard time differs from Greenwich Mean Time (for example, to convert Pacific Standard Time to GMT, add 8 hours).

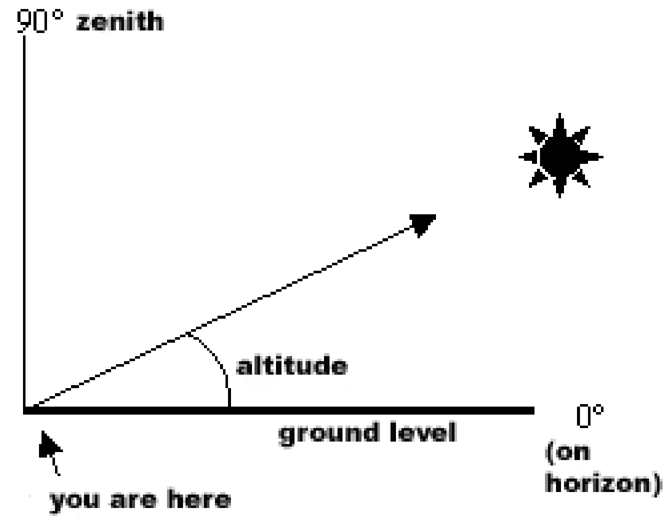
Information for Teachers

Altitude and Azimuth

In order to measure an object's position in the sky, you need to know about *altitude* and *azimuth*.



Azimuth: The angle measured along the horizon from geographic north to the point directly below an object.

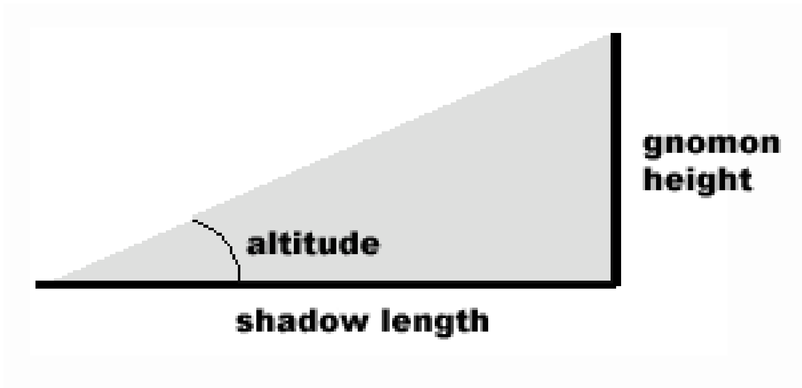


Altitude: The angle measured from the point on the horizon below an object straight up to the object.

Altitude and azimuth are coordinates describing the angular position of an object in space, relative to a central point (the position of an observer on the surface of the Earth). The altitude of an object is the angle, measured in degrees, between the point on the horizon directly below the object straight upward to the object. The azimuth of an object is the angle measured *along* the horizon from geographic north to the point on the horizon directly below the object.

Calculating Altitude Using Trigonometry

For students who like to use trigonometry, the altitude of the Sun can easily be calculated from the height of the gnomon and the length of its shadow, assuming that the gnomon is perpendicular to the dial on which the shadow is cast (as it's supposed to be). The gnomon and its shadow form the legs of a right triangle, as shown below. The hypotenuse of the triangle is the line drawn from the gnomon's top to the tip of its shadow. To calculate the altitude angle, calculate the ratio of the gnomon height divided by the shadow length and take the inverse tangent of this ratio. This gives the altitude.

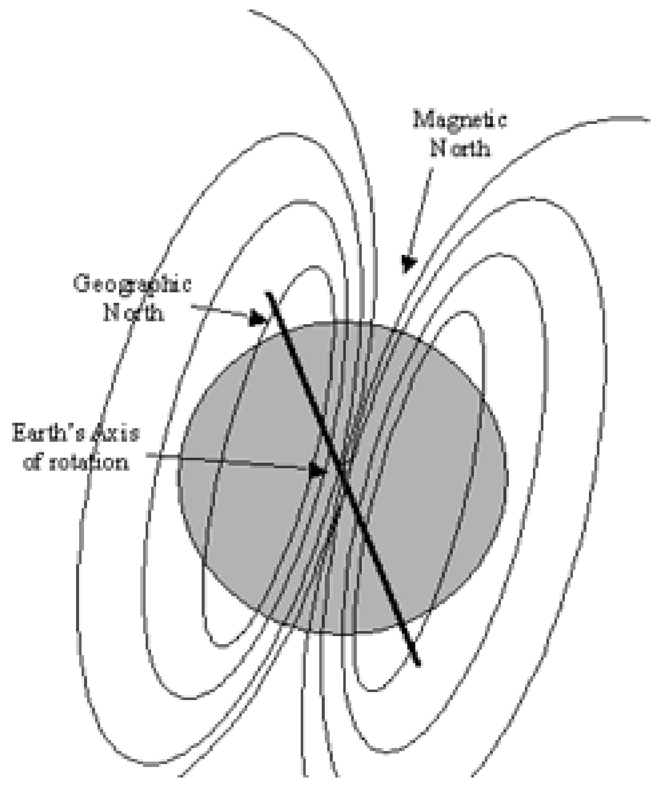


altitude = $\tan^{-1}$ ((gnomon height) / (shadow length))

Magnetic Declination

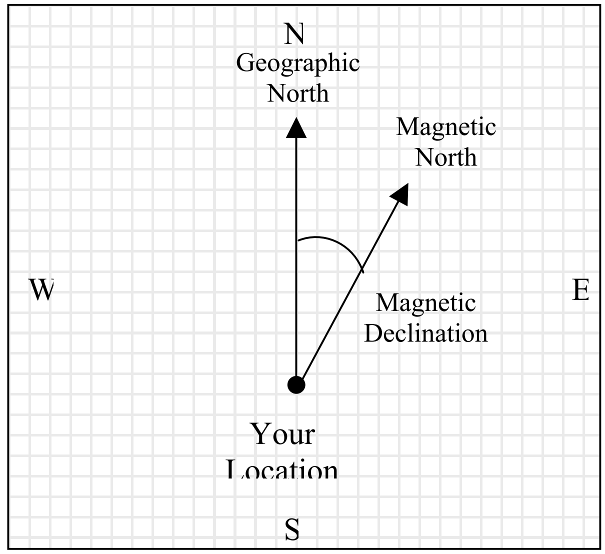
If the Earth's geographic poles and the magnetic poles were in the same locations then a magnetic compass would point exactly in the direction of the geographic North Pole. However, the geographic poles and the magnetic poles are not in the same places on the Earth.

You may use a magnetic compass to align your instrument with geographic north. To be able to do this correctly, you need to know the *magnetic declination* of your location on Earth. Most topographical maps contain a directional legend showing the local magnetic declination. Learn more about this topic at the United States Geologic Survey website (see Web Resources in Introduction).



Above: Cross-section of the Earth, cut through the geographic and magnetic axes. The axis of rotation (geographic axis) and the magnetic axis are not parallel, and so their "poles" (where they meet the Earth's surface) are not at the same locations.

Geographic North: This is the direction of the Earth's geographic north pole as seen from a given location on Earth. Geographic north is used to reference directions of travel along the Earth's surface. The Earth's Geographic Poles are the points where the Earth's *axis of rotation* and surface intersect.

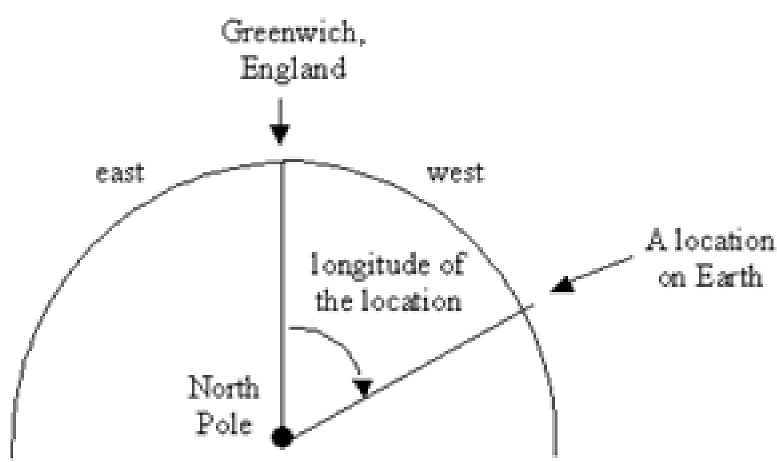


Magnetic North: The direction of the pole of the Earth's magnetic field in the Northern Hemisphere as seen from a particular location on Earth. Magnetic compass needles point to the Earth's magnetic poles.

Magnetic Declination: From a given location on Earth, the magnetic declination is the angle measured from true (geographic) north to magnetic north. For example, in the San Francisco Bay Area the magnetic declination is about 17 degrees <u>east</u> of north. In other words, in the San Francisco Bay Area a magnetic compass needle will point 17 degrees to the east of (to the right of) true geographic north.

Longitude, Local Noon, and GMT

A *meridian* is a line drawn on the Earth's surface from the North Geographic Pole to the South Geographic Pole. Any two locations that are east or west of each other, even by a small amount, are on different meridians.



The *Prime Meridian* is the meridian that runs through Greenwich, England. The longitude of Greenwich is 0 degrees.

Longitude is the angle measured east or west from the Prime Meridian to another meridian.

A location to the east of the Prime Meridian has a longitude expressed in "degrees east," while a location to the west is so many "degrees west" of Greenwich's meridian.

Local noon is the time when the Sun reaches its highest point in the sky during the day at a given location on Earth. Local noon does not necessarily occur at 12:00 o'clock, as you might think. "12:00 o'clock noon" by the clock is merely a *standard noon* agreed upon as noon for everyone living within a particular "slice" of the Earth between two meridians, called a *standard time zone*. Since the Earth rotates smoothly and continuously, the clock time at which *true* local noon occurs may be different for you than for someone on a different meridian—even if you and that other person are within the same standard time zone (your clocks will agree when 12:00 o'clock occurs, but the times of true local noon will differ).

Luckily, if you measure the time at which the Sun reaches its highest point (true local noon) and convert that time to Greenwich Mean Time, you don't have to worry about zone time.

Imagine this: It is local noon in Greenwich, England. Local noon occurs at 12:00 GMT for Greenwich. As the Earth rotates (once in 24 hours with respect to the Sun) the meridian on Earth that the Sun is directly over "moves" to the west, at a rate of 360 degrees of longitude (one full circle around the Earth) every 24 hours—or <u>15 degrees per hour</u>. One hour after local noon in Greenwich, true local noon occurs for the meridian 15 degrees to the west of Greenwich.

Question: If the longitude of your city is 150 degrees west of Greenwich, what will be the time in Greenwich (the GMT) when true local noon occurs for you?

> Answer: If the GMT is 12:00 when the Sun passes directly over Greenwich's longitude, and the meridian at which local noon occurs moves off to the west at 15 degrees per hour, then the Sun reaches local noon at 150 degrees west longitude 10 hours later, or at 22:00 GMT (10:00 PM on the 12-hour clock). 15 degrees per hour times 10 hours is 150 degrees.

Question: You measure the GMT when the Sun reaches true local noon to be 4:30 GMT. What is your longitude?

> Answer: 4:30 GMT occurs 7 hours and 30 minutes <u>before</u> 12:00 GMT, so local noon at Greenwich will occur 7 hours and 30 minutes

(7.5 hours) after it occurs at your meridian. Since the GMT of your local noon is before 12:00 GMT, you are east of Greenwich. If the point at which it is local noon moves 15 degrees per hour westward, then you are 7.5 hours times 15 degrees per hour = 112.5 degrees east of Greenwich. Your longitude is 112.5 degrees east.

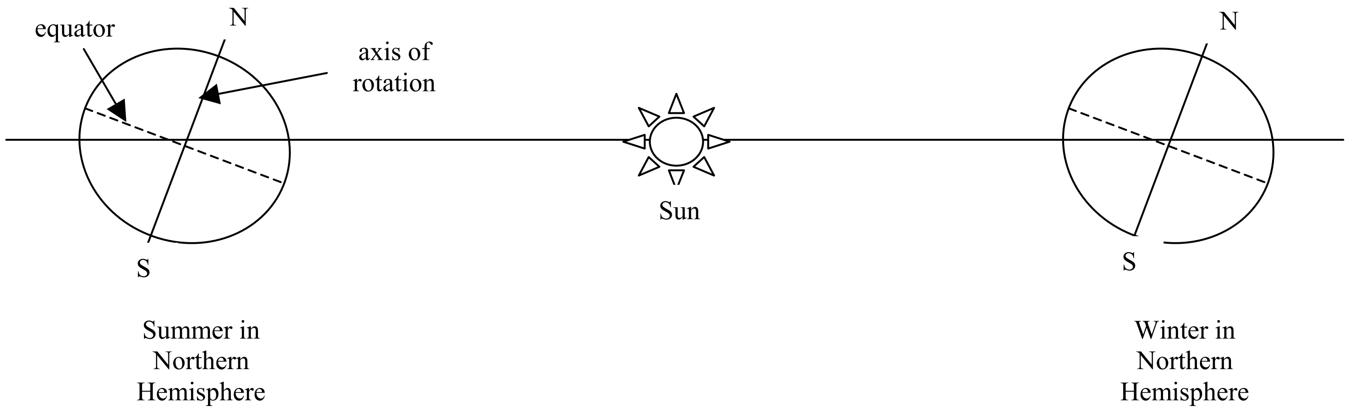
Latitude, Sun Angle, and the Earth's Axial Tilt

Latitude is the angle between the Earth's equator and a given latitude on the Earth, measured directly northward or southward. Locations on the equator have a latitude of 0 degrees. Moving north, toward the North Pole, the latitude increases, up to 90 degrees (the latitude of the North Pole). Northern latitudes are expressed as so many degrees "north." In the Southern Hemisphere, latitudes are expressed in "degrees south."

The altitude of the Sun (the angle measured from the horizon straight upward to the Sun) depends on two factors: the time of day and the day of the year. The relationship between time of day and altitude of the Sun is easy to see: it changes all day long, being zero degrees at sunrise, climbing through the sky for half the day to reach a maximum altitude, then falling toward the western horizon during the afternoon and again reaching zero altitude at sunset.

The dependence of Sun altitude on time of year is a little more complicated. To make things easier, we will discuss the Sun altitude at true local noon—the highest altitude that the Sun reaches on a given day.

The Sun's maximum altitude varies throughout the year due to the fact that the Earth's axis of rotation is tilted—about 23.5 degrees—with respect to the plane in which the Earth orbits the Sun. During the Northern Hemisphere's summer, the Sun passes directly overhead in northern latitudes. At true local noon on the Summer Solstice the Sun has an altitude of 90 degrees for people located on the Tropic of Cancer, at a latitude of 23.5 degrees north. Six months later, at the Winter Solstice, the Earth has gone halfway around the Sun and now people at the Tropic of Capricorn (a latitude of 23.5 degrees south) see the Sun pass directly overhead at true local noon.



Because of the tilt of the Earth's axis of rotation, the maximum altitude of the Sun changes constantly throughout the year for a given location.

To determine your latitude from a measurement of the Sun's altitude at your true local noon, you need only to perform simple math. It is easiest to do this experiment at or near a solstice (Summer or Winter), but it can be done any time of year as long as you can determine for any given day the latitude at which the Sun passes directly overhead.

The equation is:

yourLatitude = 90 – sunAltitudeAtLocalNoon + latitudeWhereSunIsDirectlyOverhead

The value of *sunAltitudeAtLocalNoon* is the value that you measure for the Sun's maximum altitude (i.e., at true local noon), and the value of *latitudeWhereSunIsDirectlyOverhead* depends on the day of year. On the Summer Solstice (June 20th), this value is 23.5 degrees. At Winter Solstice (December 21st), the value is –23.5 degrees. (Though the value of the latitude where the Sun passes directly overhead changes from day to day, it changes more slowly around the solstices than at any other time of year, so you can use the numbers given here for a week or so before and after a solstice.) See the Analemma graph in the next section to determine the "subsolar latitude" for any day of the year.

How To Determine True Local Noon

Of course the best way to determine the exact time of your true local noon is to measure it very accurately, such as with a sundial…but since that measurement is the subject of this activity, you need to determine the true local noon at your location independently, for comparison. This section is an explanation and cookbook method of how to do this.

There are three basic steps to calculating the true local noon of your location. In a nutshell (and explained in more detail below):

1. Time Zone Meridian: Multiply the difference in hours between your time zone time and that of Greenwich (GMT) by 15 degrees. This will give you the longitude (east or west of Greenwich) of the meridian at which your time zone is based.
2. Your Meridian: Find your longitude, converting to decimal form if necessary.
3. Difference: Find the difference between the longitudes of your Time Zone's meridian and your meridian and divide that difference by 15 degrees per hour. This will give you the time difference between the true local noon of your Time Zone's meridian and the true local noon of your meridian.
4. Add or subtract the difference above from 12:00 noon to get your true local noon. If your longitude is west of your Time Zone's meridian, add the difference, otherwise subtract it. But wait! You're not done yet. You must make a correction for the Analemma, described below.
5. Analemma Correction: Once you correct for the Analemma, your result should be your true local noon!

Time Zone Meridian

The standardized clock time for your time zone is based on the true local noon at a specific meridian within your time zone. Though the actual boundaries on the east and west sides of a time zone can vary drastically depending on where in the world you are (sometimes following national borders or geographic features), the standard time of most zones is set to the true local noon of a meridian in the middle, more or less, of that zone. The boundaries of a time zone—the borders at which you would change your clock when traveling between zones—lie at the edges.

In general, the meridians of the Earth to which time zone times are standardized are spaced 15 degrees of longitude apart, starting at Greenwich, England. Therefore the meridians whose true local noons are used as the standard time for their time zones are located at 0, 15, 30, 45, 60, 75, 90, 105, 120, 135, 150, 165, and 180 degrees longitude, east and west of Greenwich. Since these meridians are exactly 15 degrees apart, the true time difference between them is exactly 1 hour from one of these meridians to the next (Earth rotates at 360 degrees per 24 hours, or 15 degrees per hour).

Consult a time zone map to determine which of these meridians is the basis for your time zone's standard time. If you know the time difference between your zone and GMT (Greenwich Mean Time), then you can calculate the standard meridian in your time zone. For example, the Pacific Time Zone is –8 hours (west) from Greenwich. 8 hours x 15 degrees per hour is 120 degrees. The Pacific Time Zone, then, is based on the true local noon at the meridian 120 degrees west of Greenwich.

Your Meridian

The next step is to obtain the longitude of your location. This you must look up. As an example, the longitude of Oakland, California, is 122 degrees and 19 minutes, or 122 + 19/60 = 122.316 degrees.

Zone Time and Local Time Difference

The difference between your longitude and that of your Time Zone's standard meridian is also the difference in time between the true local noons of those two meridians—it just has to be converted from degrees of longitude to hours of the day. For example, the difference in longitude between Oakland, California and the Pacific Time Zone's standard meridian (120 degrees west) is 122.316 – 120.000 = 2.316 degrees. Since the Earth rotates 15 degrees per hour, then the time difference between when the Sun is at true local noon over the Pacific standard meridian and the meridian of Oakland is 2.316 degrees / 15 degrees per hour = 0.1544 hours, or 9.264 minutes. Note that Oakland is west of the standard meridian, and so its true local noon occurs after that of standard time—9.264 minutes after. So, true local noon occurs at Oakland at 12:09 PM (seconds rounded off) (or 1:09 PM during Daylight Savings Time).

But wait! You're not on time yet. The method for calculating true local noon above is based on the assumption that the Sun moves steadily and continuously through the sky, without changes in speed. In fact, it does not.

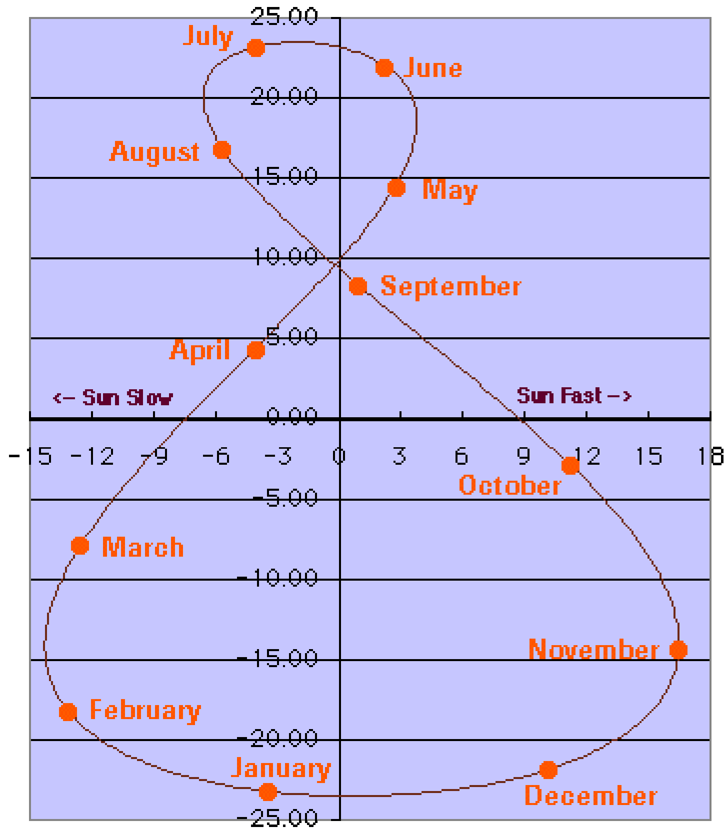
Analemma Correction

The time at which the Sun arrives at its highest altitude in your sky changes from day to day over the course of the year. The reasons for this will not be discussed in detail here, but you should be aware that, depending on the day of the year, the exact time of true local noon will change.

In brief, there are two separate effects going on that cause this variation: the Earth's 23.5 degree tilt on its axis and the Earth's non-circular, elliptical orbit around the Sun.

Each of these things contributes to the variation in true local noon. The combination of the variations can be combined in one easy-to-read graph, called an Analemma.

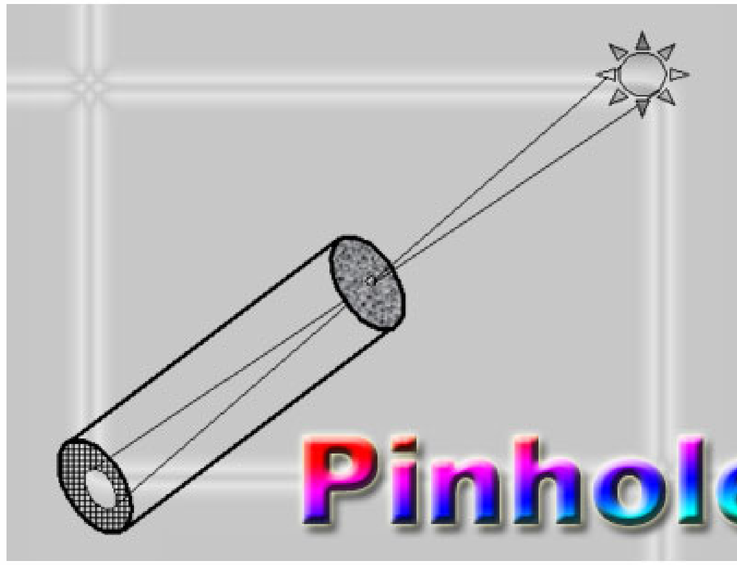
To the right is an Analemma that you can use to get the correction for your calculated true local noon. Simply find the time of year on the figure-eight curve and read from the horizontal axis the number of minutes indicated. For instance, if it's March 1st, locate March on the curve and read from the horizontal axis, in this case about –13 minutes. (If you're some time in the middle of the month, try to interpolate the exact date on the curve—for instance if it's March 15, locate the point on the curve midway between March and April; in this case the time difference read from the horizontal axis is about –8 minutes.)



ANALEMMA CURVE

A **negative** value for the correction means that the Sun is "running slow," and so true local noon (when the Sun finally reaches its highest altitude) will be that many minutes later and so you would add that number of minutes to your calculated true local noon. A **positive** value means that the Sun is "running fast," and so will reach its highest altitude that many minutes sooner, and so you would subtract that many minutes from your calculated true local noon.

The vertical axis shows the "subsolar latitude" on that date—the latitude at which the Sun is directly overhead (at the zenith). Though the subsolar latitude is not important for determining the Analemma correction, it is useful for the activity of pinpointing your location on Earth from your sundial measurements.



Pinhole Camera

All the Sun through the eye of a pinhole

Solar-B Education and Public Outreach (EPO)

Solar-B is a multinational solar observatory satellite project headed by the Japanese Space Agency (ISAS), in partnership with the United States (NASA) and the United Kingdom (PPARC).

The Solar-B EPO program at Chabot Space & Science Center is funded by a grant from the Lockheed-Martin Solar and Astrophysics Lab (LMSAL) in Palo Alto, California.

The activities and materials in this package were developed for the *Touch the Sun* teacher-training workshop at Chabot Space & Science Center, 10000 Skyline Blvd., Oakland, California 94619.

Pinhole Camera

Nuts and Bolts

What Students Will Do

- Build a specialized, Sun-measuring *pinhole camera*.
- **Safely** observe the Sun with the pinhole camera and record image size measurements.
- Calculate the diameter of the Sun from your measurements and a known distance to the Sun.

Key Concepts

- Light rays tend to travel in straight lines.
- Light rays emitted or reflected by an object that pass through a small hole can project an image of the object on the other side.
- An image of an object can be used to determine the object's size or the distance to the object.
- The ability of the human eye's lens to focus an image on the retina is aided by the eye's pupil (the eye's aperture), which acts as a pinhole camera.

Materials Needed

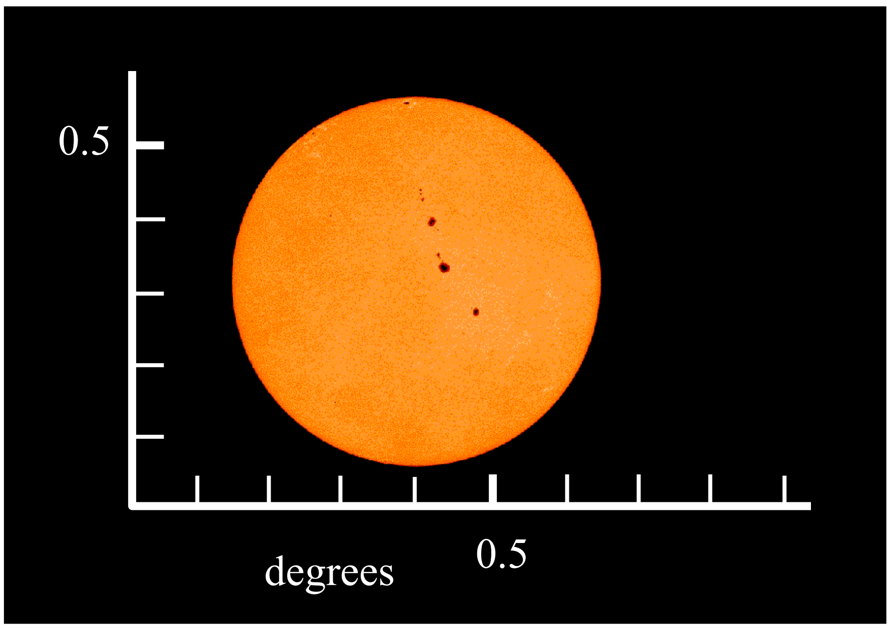
- Cardboard tube (the longer the better)
- Cardboard tube scraps
- Aluminum foil
- A sharp pin
- Tape
- Graph paper (with millimeter grid)

Introduction

Description

Solar-B will use mirrors, lenses, CCD cameras, and other optical components to form images of the Sun. From these images the sizes of objects and events on the Sun – and the Sun's disk itself – can be measured.

You will measure the diameter of the Sun using aluminum foil, a cardboard tube, graph paper, and a pin!

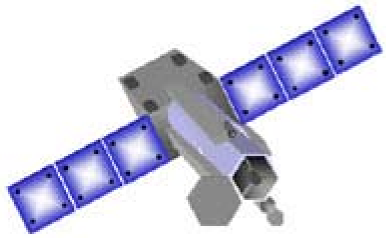


Above: The disk of the Sun shown with a scale of angular separation on the sky. The Sun's disk is approximately one half degree across as seen from Earth.

A pinhole camera is the world's simplest image-forming device. You may believe that the only way to take a picture is with an expensive set of lenses and other mechanical accessories. After all, human eyes and cameras and telescopes all use intricate optics to function as they do. Would you believe that a simple pinhole in a piece of foil or paper would do the trick!

Light shining from an object (the Sun, the Moon, a traffic light, a person) through a small pinhole will form an image of the object on the other side, much as a camera's lens forms an image of an object on the sheet of film behind the lens. In this case, however, the pinhole serves as the lens.

Solar-B Connection

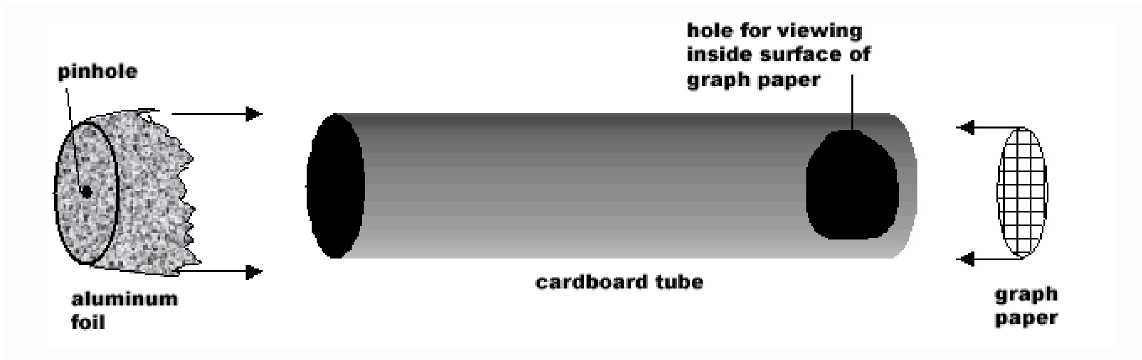


An important part of the work to be done by Solar-B scientists will be the measuring of motion of the materials on the Sun. One of the main subjects of study will be how events and processes such as sunspots, solar magnetic fields, flares, prominences, and other dynamic solar features are born, develop, and dissipate. A complete picture of the life cycle of these events will be possible with the data collected by Solar-B.

Cameras on Solar-B will take series of images of the Sun's surface, and the motion of materials and magnetic fields will be seen and measured through comparisons of the images.

Build It

Step by Step



Pinhole Camera: Assembly Diagram

1. Find and/or assemble the tube. The tube should be at least 30 inches long, but even longer is better. (Gift-wrap-paper cardboard tubes can be used, either in single lengths or taped together end-to-end.)
2. Near one end of the tube (half an inch or less from the end), cut out a hole. The hole should be large enough so that you can see most of the opening at the end of the tube from the inside.
3. Cut out a piece of lined graph paper (with a millimeter grid spacing, if possible) just large enough to fit in one end of the tube.
4. Tape the graph paper to cover the opening at the end of the tube—the same end in which you cut the viewing hole.
5. Cut out a piece of aluminum foil just large enough to fit on the end of the tube opposite the graph paper. (Or you could cut out a larger piece that can be wrapped over the end of the tube, as shown in the diagram.)
6. Tape the foil to the end of the tube opposite the graph paper. Note: It is important that the foil be smooth, flat, and taut, like a drumhead.
7. Using a sharp point no bigger than that of a pin, poke a very small hole in the center of the aluminum foil.
8. Your pinhole camera is ready to use!

Observe

Your pinhole camera has been designed specifically to measure the diameter of the Sun. Before you observe the Sun with it, repeat the following sentence one thousand times:

I will not look directly at the Sun!

It is very important that you do not look directly at the Sun, not with a telescope, not with a camera, not with a pair of binoculars, and not with your pinhole camera. The design of you pinhole camera makes it easy to measure the size of the Sun's image without being in danger of accidentally letting direct sunlight into your eyes. When you point the tube at the Sun and look into the viewer, you are looking away from the Sun, which is always the safest thing to do.

Step by Step

1. Stand facing **away from the Sun**.
2. Lift the viewer hole to your eye and point the tube over your shoulder in the direction of the Sun.
3. Try to find the Sun's image on the graph paper, looking through the viewing hole.

   When your pinhole camera is pointed properly at the Sun, you will see a small spot of light on the graph paper. The size of the spot will depend on the length of your pinhole camera.

   If you have difficulty finding the Sun's image (which will be a small and possibly faint spot of light on the graph paper) there is a trick you can try: Look at the shadow that your pinhole camera tube casts on the ground and move the camera around until its shadow is as small as possible. When the tube is pointed directly at the Sun, its shadow will be at its smallest.
4. When you find the Sun's image, attempt to measure its size by counting the number of millimeter lines on the graph paper that it covers, from edge to edge (the image's diameter). Make as careful a measurement as you can.

If you have trouble reading the size of the Sun's image because you cannot hold the camera still enough, try resting the camera on some solid object (a table, a chair, a window sill).

5. Record all of your measurements on the Data Sheet.

Data Sheet

Measure the length of your tube from pinhole to projection screen. You should be accurate to the nearest 0.1 centimeter and then convert to meters by dividing by 100. Example: 65.2 cm = 0.652 m.

____

Measure the height of your image of the Sun on the millimeter grid. Make at least three measurements and average your results. Show your work and record your result in millimeters. (This is the "h" value.)

Trial #1__________ Trial #2__________ Trial #3__________

____

Convert the Sun image height to meters by dividing by 1000. Example: 8.5 mm = 0.0085 m. Show your work.

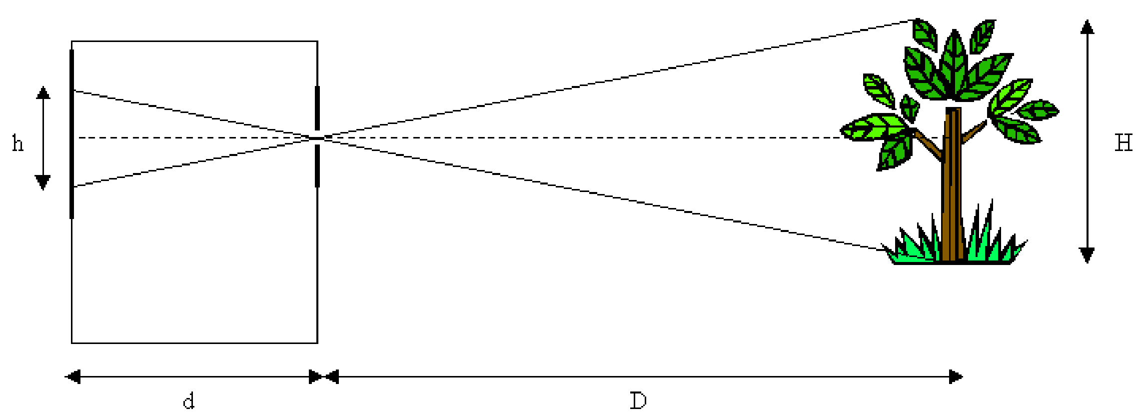
____

The mean distance to the Sun (your "D" value) is 1.496×10^{11} meters (about 93 million miles).

For a pinhole camera, the relationship between the object size, the object distance, and the length of the camera is simple:

$$H / D = h / d$$

where H is the actual height (diameter) of the Sun, D is the distance to the Sun, h is the height of the Sun's image on your projection screen, and d is the length of your camera tube.



The diameter of the Sun, H, can be expressed as:

$$\mathbf{H = D\ (\ h/d\ )}$$

Using your values for D, h, and d, calculate the diameter of the Sun. Carefully show the setup and all of your work here. Make sure all of your numbers are in meters, and your answer is in scientific notation rounded to two decimal places. Example: 7.36×10^6 meters.

____

Questions

1. How close to the actual value is your value for the diameter of the Sun? In other words, was it within 0.1×10^9 meters, or not?

2. What could have caused your answer to be inaccurate?

3. How close to the class average is your value for the diameter of the Sun?

4. Explain how pinhole cameras of different lengths can achieve similar results for the diameter of the Sun.

Lessons Learned / Questions / New Ideas

Now that you have experienced the process of building, using, and analyzing data from a Sun-size measuring pinhole camera, write down all of the things that you would do differently (if anything) if you were to build another.

1. What would you do to improve the design of your camera (its size, dimensions, measurement surface, pinhole)?
2. What would you do to improve the construction of your camera (the materials used, the methods of attaching everything together)?
3. What would you do to improve the way in which you use the camera to collect data from the Sun?
4. How do you think any of these changes would improve the ease of use and accuracy of the data collected?

Additional Activities

Instrument Improvement

Pinhole Size

Determine the effect of pinhole size on Sun image size.

Poke three holes, of different sizes, into the aluminum foil at your pinhole camera's aperture end. Try using a thumbtack to make one of the holes, a pinpoint for another, and perhaps a very thin, sharp staple for a third. Space the three holes about a centimeter apart from one another.

Observe the Sun with your triple-pinhole camera. Measure the image size for each of the three holes.

Calculate the Sun's diameter for each image size. Answer the following questions:

1. Is there a difference in the calculated diameter of the Sun for each of the different pinhole sizes? If so, what is the difference? Plot your results on a graph of Sun diameter versus pinhole size.
2. How important is pinhole size in producing accurate measurements?
3. Is there a difference in the brightnesses of the images produced by each pinhole? If so, why is this?

The larger the pinhole, the more out of focus will be the image of the Sun's disk. Smaller holes produce sharper images, and more accurate results.

Camera Length

Modify your pinhole camera to give it a different length (a different distance between pinhole and graph paper).

Measure the size of the Sun again and record your results. If you have created three different-sized pinholes for the previous experiment, go ahead and make measurements for all three.

Calculate the Sun's diameter from your measurements. Compare the results to those you obtained with the original pinhole camera.

Note: It is important that when you compare the results from cameras of different lengths, you compare the results using the same pinhole apertures in each case. If you have built a new camera to do this experiment, then you either need to transplant the aluminum foil with the pinhole from your first camera, or take great care in making the pinholes the same size.

1. Is there a difference in the results?
2. Which camera, if any, produced more accurate results?
3. If one of the cameras did produce more accurate results, why do you think it did?

Sun's Angular Size

Note: This activity uses trigonometry.

Given the size of and mean distance to the Sun, as listed in the Appendix of this section, calculate the angular size, A, of the Sun using trigonometry:

$$\mathbf{A = 2 \tan^{-1} [H / (2D)]}$$

The Earth does not orbit the Sun on a perfect circular path, but on a slightly elongated ellipse. This means that at different times of the year, the Earth is closer to or farther away from the Sun than the *mean* distance. The time when the Earth is closest to the Sun is called *perihelion*, and the time when it is farthest from the Sun is called *aphelion*. The values for the perihelion distance and aphelion distance are listed in the Appendix of this section.

Calculate the angular size of the Sun at (1) perihelion and (2) aphelion. Present the two results by drawing properly scaled, concentric circles using a drawing compass. You can represent the angular sizes in degrees in terms of inches or centimeters on the paper you draw on.

Example: Drawing in centimeters, with a conversion factor of 1 degree per 10 centimeters. If the angular diameter of the Sun you have calculated is 0.4 degrees across, then the diameter of the circle you draw on paper is 0.4 degrees times 10 centimeters per degree, or 4 centimeters.

Draw both circles using the same center point.

Does the difference in the distance to the Sun between perihelion and aphelion make a big difference? Do you think you would be able to measure the difference using your pinhole camera?

Information for Teachers

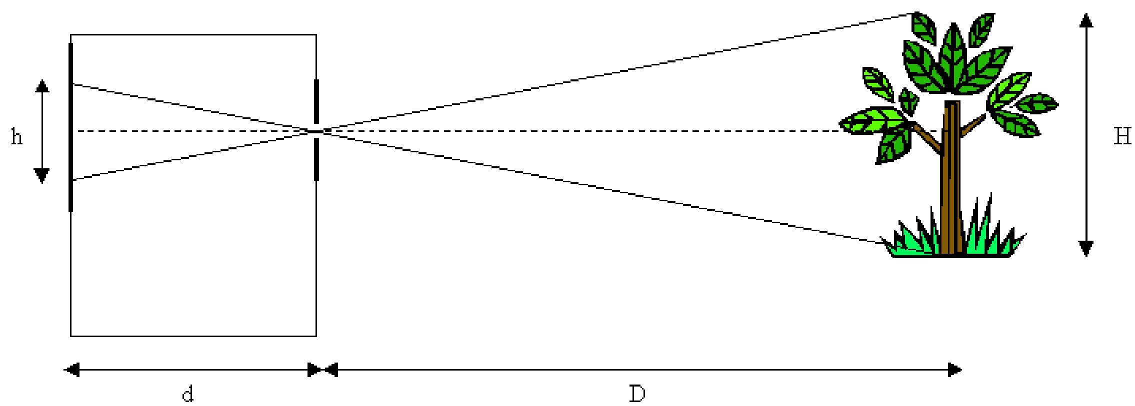
The size that objects appear in the field of view of a magnified imaging system (a camera, a telescope) depends on the actual size of the object, the distance to the object, and the magnification of the imaging system. Though a pinhole camera uses no optics, the size of the images it produces still depends on three factors: object size, object distance, and the *length of the pinhole camera* (the distance from the pinhole aperture to the projection surface).

Ratio Method

For a pinhole camera, the relationship between the object size, the object distance, and the length of the camera is simple:

$$\mathbf{H / D = h / d}$$

where H is the actual size of the object, D is the distance from the pinhole camera aperture to the object, h is the size of the object's image in the pinhole camera, and d is the distance from the pinhole camera aperture to the image projection surface.



Relationship between image height h, projection distance d, object distance D, and object height H

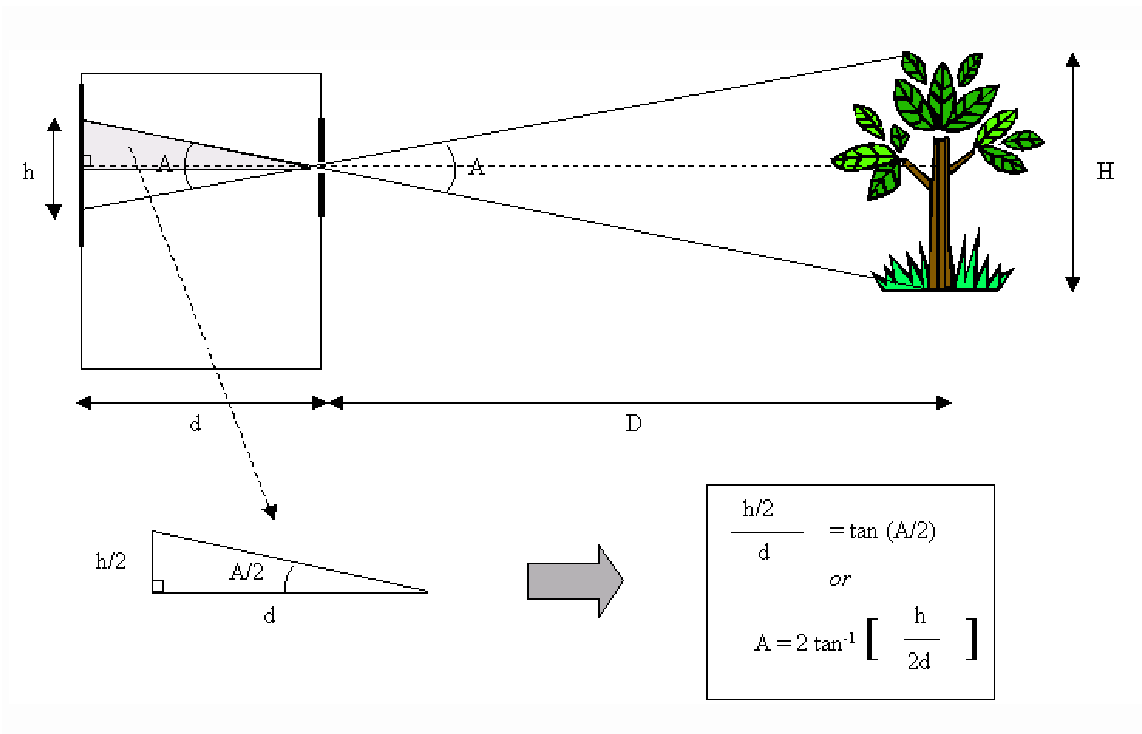
For the purpose of measuring the diameter of the Sun (D), the distance to the Sun (H) has to be known (obtained by some other means; see the Appendix of this section for the Sun's mean distance from Earth).

The length of the pinhole camera, d, can be measured with a ruler, leaving only the size of the image of, h, as an unknown. This value, h, is what is measured with the pinhole camera. The diameter of the Sun, D, can be expressed as:

$$D = H\ (d / h)$$

Trigonometric Method

Another method of calculating H is by trigonometry. Other than exercising your skills in trigonometry, the only real advantage to using this method is that it allows you to express the apparent *angular size* of the object without knowledge of the true size or distance. The trigonometric solution makes use of the geometry shown below by forming a right triangle from half of the image size and the pinhole camera length.



Knowing the *angular* size of an object is useful. Unlike the direct image size on the pinhole camera projection surface, the angular size is independent of whatever camera or device that measured it.

The next step along the trigonometric road is to apply the reverse of the equation to the geometry of the actual object's size and distance, H and D. Start by using the same equation, which becomes:

$$\mathbf{(H/2) / D = tan\ (A/2)}$$

Solving for H (assuming that D, the distance to the Sun, is known; see the Appendix), the Sun's size is:

$$\mathbf{H = 2\ D\ tan\ (A/2)}$$

Appendix A

The Sun's Dimensions

Mean Distance to the Sun—kilometers: 149,597,870

Mean Distance to the Sun—miles: 92,960,116

Diameter of the Sun—equatorial, kilometers: 1,392,530

Diameter of the Sun—equatorial, miles: 865,318

Perihelion Distance to Sun—kilometers: 146,605,913

Aphelion Distance to Sun—kilometers: 152,589,827

Fingerprinting the luminous suspects

Solar-B Education and Public Outreach (EPO)

Solar-B is a multinational solar observatory satellite project headed by the Japanese Space Agency (ISAS), in partnership with the United States (NASA) and the United Kingdom (PPARC).

The Solar-B EPO program at Chabot Space & Science Center is funded by a grant from the Lockheed-Martin Solar and Astrophysics Lab (LMSAL) in Palo Alto, California.

The activities and materials in this package were developed for the *Touch the Sun* teacher-training workshop at Chabot Space & Science Center, 10000 Skyline Blvd., Oakland, California 94619.

Spectroscope

Nuts and Bolts

What Students Will Do

- Explore how a diffraction *grating* affects light.
- Understand that the different colors seen through the grating correspond to different *wavelengths* of light.
- Build a simple grating spectroscope, with a scale for measuring wavelengths.
- Observe different sources of light with your spectroscope and record their spectra.
- Identify specific spectral lines found in more than one type of light source.
- Analyze the collected data.

Key Concepts

- Light has wave-like properties.
- The distance between successive wave “crests” in a light wave is the wavelength of the light.
- The wavelength of light waves is very small, and usually measured in nanometers.
- 1 nanometer = 1 billionth of a meter; 1 billion nanometers equals 1 meter.
- Light waves normally travel in straight lines.
- The direction of a light wave’s travel can be changed by the phenomena of reflection, diffraction and refraction.
- The amount by which a light wave’s direction of travel is changed by diffraction or refraction depends on the wavelength of the light.
- A spectrum is a range of values or properties: the electromagnetic spectrum is the range of all possible wavelengths of light; the visible spectrum is the range of all wavelengths of light that the human eye can detect; the wavelengths of light present in a given source of light is that source’s spectrum.

- With special instruments such as spectroscopes we can separate the different wavelengths of light and learn exactly what wavelengths are present in a given source of light.
- The wavelengths of light present in a light source can tell us what *chemical elements* emitted the light.

Materials Needed

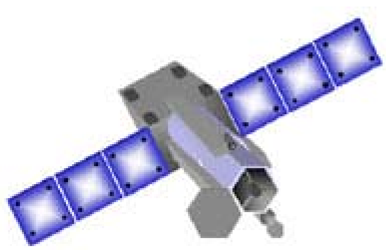
- A diffraction grating
- A frosted incandescent lamp
- A fluorescent lamp
- Additional light sources (gas emission lamps. neon lamps, LEDs)
- A small box (a shoebox is perfect)
- Scissors
- Utility knife
- Tape
- An aperture. A pair of straight, thin, opaque objects placed edge to edge to form a narrow gap, or slit, between is good. Sometimes razor blades are used, but a pair of playing cards or other thin, opaque cardboard works well without the danger of cutting yourself.
- Graph paper

Introduction

Description

In this activity you will learn how a diffraction grating works, and you will add features and capabilities to the diffraction grating to build the instrument called a *spectroscope*. You will use your spectroscope to observe and record the spectra of different sources of light.

Solar-B Connection



One of Solar-B's most important instruments will be a *spectroscope* combined with a *polarimeter*, together called a *spectro-polarimeter*.

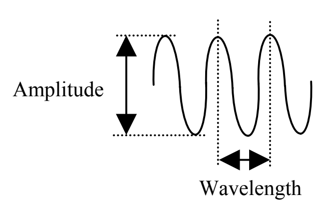
This system will allow Solar-B scientists to measure the brightness of and polarization of the light of a wide range of wavelengths simultaneously. Being able to separate the wavelengths of light is important because it allows scientists to select the light emitted by specific chemical elements, some of which are much more sensitive to the presence of the solar magnetic fields in which they are suspended.

The shape and structure of the magnetic field will be much easier to observe by measuring the polarization of the light from these "magnetically sensitive" elements.

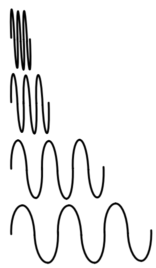
From sets of data gathered with the spectro-polarimeter, the entire life cycle of solar magnetic fields and explosive magnetic events will be captured and revealed to us.

Background

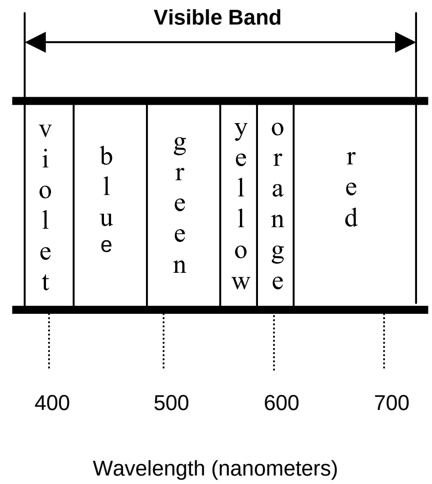
Light is a wave, like waves or ripples on the surface of water. Light, however, is a wave of *electromagnetism*, not water. That is, light is an oscillating *electric field* and *magnetic field*, traveling together. For this reason a light wave is called an *electromagnetic wave*. Light is also known as *electromagnetic radiation*.



Like water waves, which can be characterized by the height of each wave and the distance between successive waves, light waves have characteristic *amplitude* (strength) and *wavelength* (distance between waves). Light waves are also characterized by the property of *frequency*, which is how frequently the waves pass by an observer in succession (how many waves pass by an observer in a given amount of time).

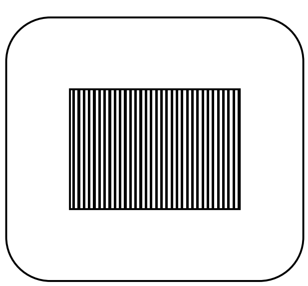


It is the wavelength (or the frequency) of a particular light wave that determines what type of electromagnetic radiation it is. The entire range of possible wavelengths of light is called the *electromagnetic spectrum*. Light of the longest wavelength (ranging from centimeters to kilometers long) we call *radio waves*. That segment of the electromagnetic spectrum is called the *radio spectrum* or *radio band* (not to be confused with a musical band heard on the radio…). At the other extreme, light with the shortest wavelengths – which measure smaller than the nucleus of an atom – we call *gamma radiation*.



The segment of the electromagnetic spectrum that we call the *visible spectrum* or *visible band* – the entire range of light that our human eyes can detect – is a very, very small portion of the entire spectrum. In wavelength, the visible spectrum ranges from 400 nanometers to 700 nanometers (1 nanometer is equal to one billionth of a meter). Our eyes perceive the different wavelengths of light in the visible spectrum as different colors. The shortest wavelength of visible light we perceive as violet. Longer and longer wavelengths we see as blue, green, yellow, orange, and red, red having the longest wavelength of the visible spectrum.

Each chemical substance – each atom and each molecule in nature – emits a very specific and <u>unique</u> set of wavelengths of light. By separating and measuring the different wavelengths (colors) of light from a source we can identify what that source is made of, even at a very great distance (the Sun, planets, stars, distant galaxies). In this way the element *helium* was detected on the Sun before it was ever discovered on Earth.



A *diffraction grating* is a tool that scientists use to separate the different wavelengths of light. You will explore what a diffraction grating does and how you can use it to build a *spectroscope* to observe and analyze the spectra of different sources of light.

Activity 1: Explore How the Diffraction Grating Works

Materials Needed

- A diffraction grating
- A frosted incandescent lamp
- A fluorescent lamp
- Additional light sources (gas emission lamps. neon lamps, LEDs)

To Do: Incandescent Light Source

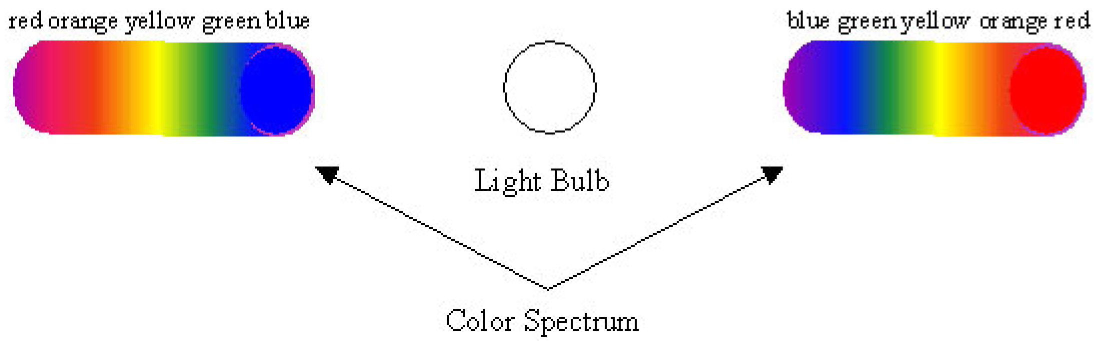
1. Turn on your frosted incandescent bulb.
2. Look through your diffraction grating at the incandescent bulb.
3. Carefully sketch what you see through the grating (you can leave out any background scenery that you see, such as walls, windows, doors, other students, etc.).

4. While looking through the grating at the bulb, rotate the grating once (a full 360 degrees). What do you notice as you rotate the grating?
5. Sketch what you observed.

To Notice: Incandescent Light Source

What you might have noticed when looking at the bulb through the grating is that there are three different things to look at (other than background scenery).

1. You can see the light bulb itself just as if you were looking through a piece of glass.
2. On opposite sides of the bulb you should see two smears of multicolored light, the colors arranged so that blue is closest to the light bulb and red farthest. You may have seen something like this:



3. When you rotate the grating, you probably notice that the positions of the color smears rotate around the light bulb, and by adjusting the rotation of the grating you can place the smears wherever you want them.

To Do: Fluorescent Light Source

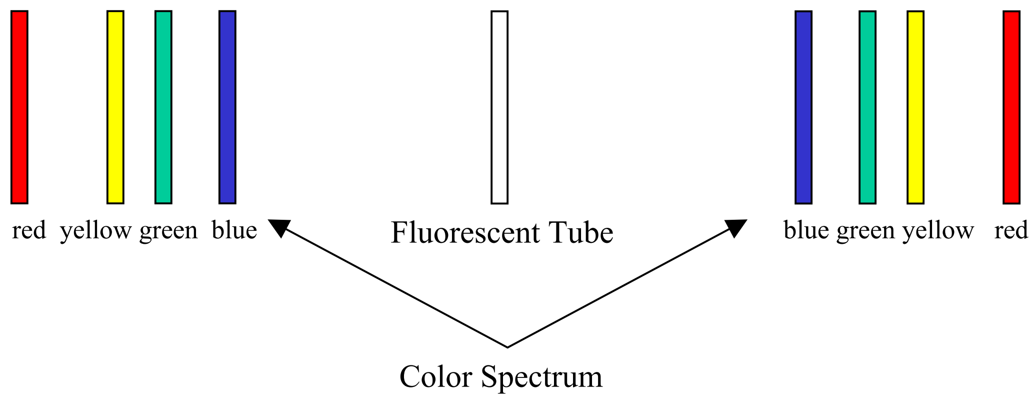
1. Turn on your fluorescent lamp tube. Most classrooms are equipped with these. Note: This activity will work much better if you have a single, bare fluorescent tube to view. If you are looking at a ceiling lamp that has a cover over it, and perhaps more than one tube in the fixture, things will be more confusing. If possible, your teacher may remove the cover.
2. View the fluorescent tube through your grating.
3. Sketch what you see.

4. Rotate the grating while looking at the fluorescent tube. What do you notice? Sketch what you see.

To Notice: Fluorescent Light Source

You might notice that what you see is similar to when you viewed the incandescent bulb, but with some differences.

You may see something different depending on how the grating was oriented. Possibly you chose a favorite orientation, and may have seen something like this:



With the fluorescent tube the color spectra on either side were not continuous smears of all colors, but separate, individual stripes of just a few colors separated by relative darkness between. The stripes, you might have noticed, were all parallel to each other, and to the fluorescent tube itself.

You might have also noticed that the shape of each color stripe was exactly the same shape as the fluorescent tube, **as if each stripe was a separate image of the tube**. This is an important point to understand: <u>each stripe *is* a separate image of the tube</u>, each one made of a different wavelength of light. If you are not certain that you saw the tube's shape in the stripes, look again.

When you rotate the grating, you may have noticed that, though all of the stripes remain parallel to each other, their distance from each other changes. You can even rotate the grating so that the stripes are all on top of each other.

To Understand: Fluorescent Light Source

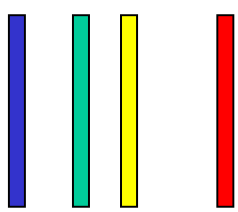
Think back over what you have done so far, both looking at the incandescent bulb and the fluorescent tube. The incandescent bulb's spectrum appeared as a continuous smear of all colors of the rainbow, while the fluorescent tube's spectrum only had a few colors, separated by relatively no light.

There are two reasons for the difference. One, the incandescent bulb, whose light comes from a hot piece of dense metal (the filament), emits what is called a *continuum spectrum*. That is, about every wavelength of visible light (every color, and every shade between) is present in the bulb's spectrum. The Sun's spectrum is also a continuum. The Sun is a ball of hot, dense gas.

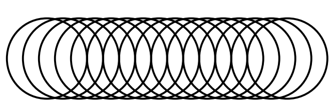
The fluorescent tube, however, contains a low density, relatively cool gas. Its spectrum is called an *emission spectrum*. In an emission spectrum, only certain wavelengths are emitted by the gas contained in the tube, with wavelengths between left dark, those wavelengths not present. (Note: You may see a faint continuum spectrum in the background, between the bright emission lines. This spectrum is coming from a phosphorescent coating on the inside of the tube that is excited by ultraviolet light emitted by the gas.)

Maybe you now understand what you are seeing when you look at the fluorescent tube through the grating: the spectra on either side of the tube are the **separate images of the tube spread out in the different wavelengths of emitted light**. There is an image of the tube in blue light only, another image in green light only, another in yellow, and so on.

The same thing is actually happening in the spectrum for the incandescent bulb. However, since the bulb emits a continuum of light (all wavelengths in the visible spectrum), the individual color images of the bulb overlap each other, blending together into one long smear. The difference is illustrated below:



The small number of colors in the spectrum of the long, narrow fluorescent tube



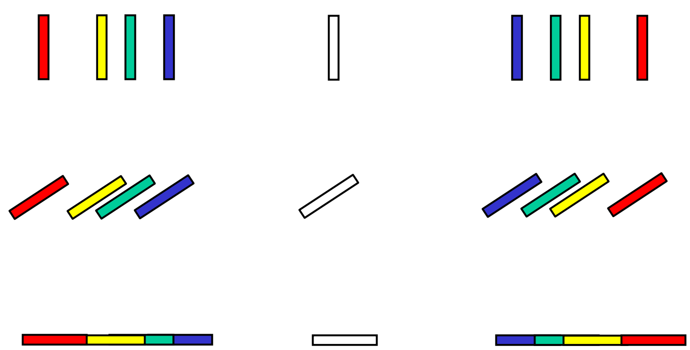
The large number of colors in the spectrum of the wide, spherical incandescent bulb, overlapping and blending together

To Do: Choosing an Aperture

1. Get a piece of opaque paper or thin cardboard and, using a scissors or a sharp knife, cut these shapes into it:

- A circular hole a centimeter in diameter
- A long, narrow slot (maybe three centimeters long and three millimeters wide)
- A distinct shape of your own choice, but only a centimeter in size (for example, a star, a moon, a cat, the number 5)

2. View the fluorescent tube through your grating and rotate the grating so that the different color images of the tube all lay end-to-end, overlapping so that the different colors are blended together as shown in the bottommost part of the picture below.



Notice how much more difficult it is to see the separate, individual colors, much as when viewing the continuum spectrum of the incandescent bulb.

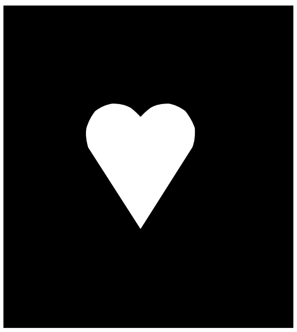
3. While still looking at the overlapping color images of the fluorescent tube, raise in front of the tube the piece of paper or cardboard in which you have cut the shapes. You may need to hunt around a bit by moving the paper, but you should eventually find the tube's spectrum again, and depending on which shape of hole the light is coming through, you will see the different colored images of that shape.
4. Sketch what you see **for each of the shaped holes** you view through.

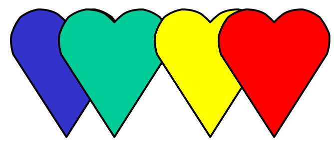
To Notice: Choosing an Aperture

You may have noticed that all of the shaped holes did a good job of separating out the individual colors: the circular hole produced a series of color circles, the narrow slot produced a series of color lines, and your chosen shape produced a set of images of that shape in the different colors of the fluorescent tube.

To Understand: Choosing an Aperture

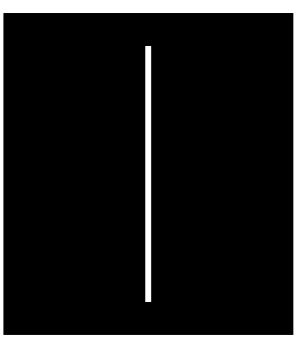
The small number of colors in the fluorescent tube's spectrum (usually from five to seven colors, depending on the type of lamp) makes it easy for shaped holes to separate the colors present in the spectrum. However, many light sources contain a great number of different wavelengths in their spectra, and so the number of color images produced by your mask may be far greater than five, six, or seven. If there are too many different wavelengths in the spectrum, the multitude of color images will overlap each other and blend together, much as the fluorescent tube's color images overlapped when you rotated the grating in the "wrong" direction.

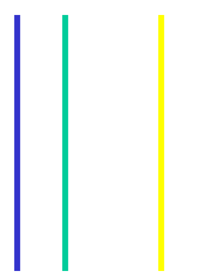




Take another look at the overlapping fluorescent tube images, and then the same as viewed through each of the different shaped holes. Imagine looking at a light source with not six, but sixty different wavelengths of light. Which of the hole shapes is most likely to produce overlapped images, and which is the least likely?

If your answer was the long, narrow slot, you're absolutely right! When rotated so that the spectrum of colored stripes are separated into a row of lines, like a row of fence posts, each narrow line easily shows the different colors in the spectrum, even when the spectrum contains a great number of lines.





You have experimented with, and hopefully have chosen, a *slit aperture* as the best way to separate out the overlapping colors in an object's spectrum. The word "aperture" essentially means "hole," and a "slit" aperture is very commonly used with a diffraction grating to analyze the wavelengths of light in a spectrum. The instrument is called a *grating spectroscope*, and you may proceed to build one in Activity 2.

Activity 2: Building a Spectroscope

Materials Needed

- A diffraction grating
- A small box (a shoebox is perfect)
- Scissors
- Utility knife
- Tape
- An aperture. A pair of straight, thin, opaque objects placed edge to edge to form a narrow gap, or slit, between is good. Sometimes razor blades are used, but a pair of playing cards or other thin, opaque cardboard works well without the danger of cutting yourself.
- Graph paper

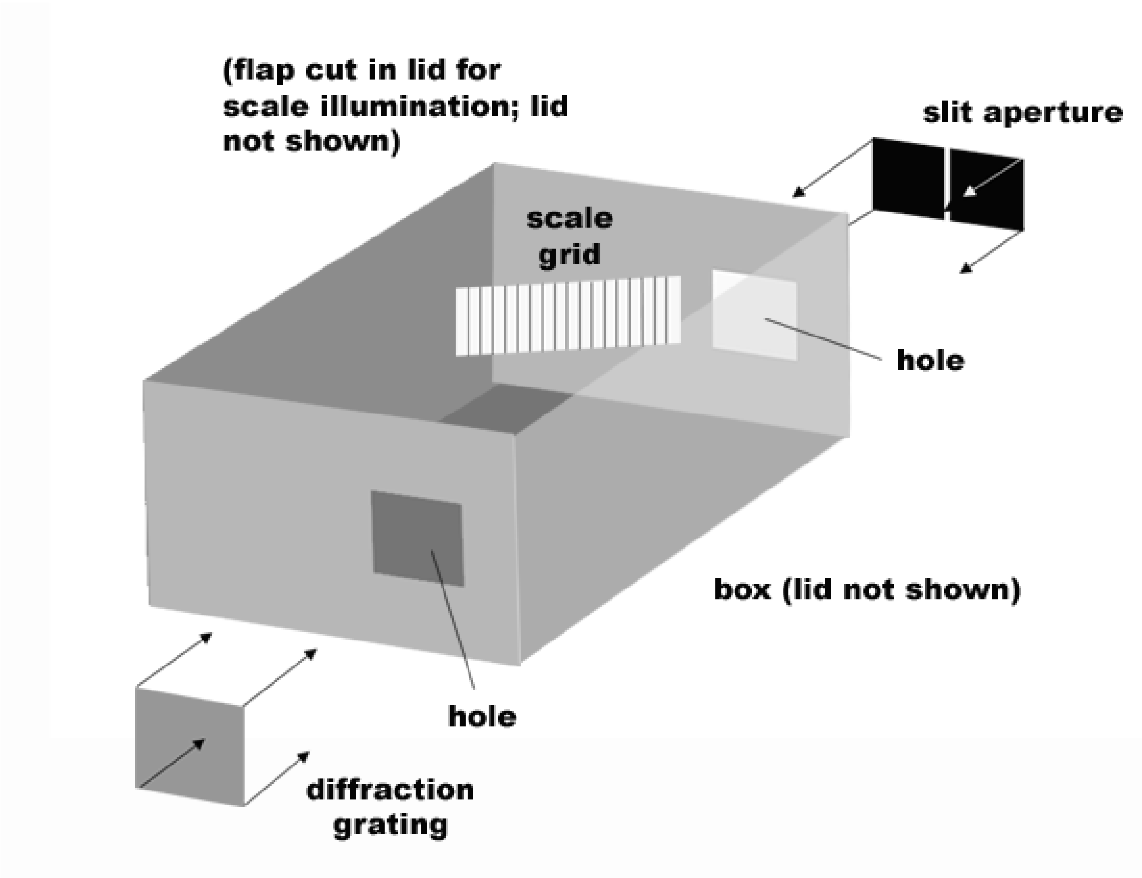
Preparation

Your spectroscope will have three main functioning parts, all held together by a box. The three parts are:

1. **Slit aperture**: A hole in one end of the box shaped like a long, narrow slit.
2. **Diffraction grating**: The grating will work just as it did in Activity 1.
3. **Scale**: A piece of graph paper placed as a backdrop to one of the two spectra the grating produces. This is for measuring the relative positions/spacing of the different lines in the spectrum.

A shoebox with a lid is a very good choice for the body of the spectroscope. If you do not have a shoebox, you can construct a box with cardboard and tape. Other objects may work as well, such as mailing tubes, paper towel tubes, hatboxes, or other boxes.

Step by Step

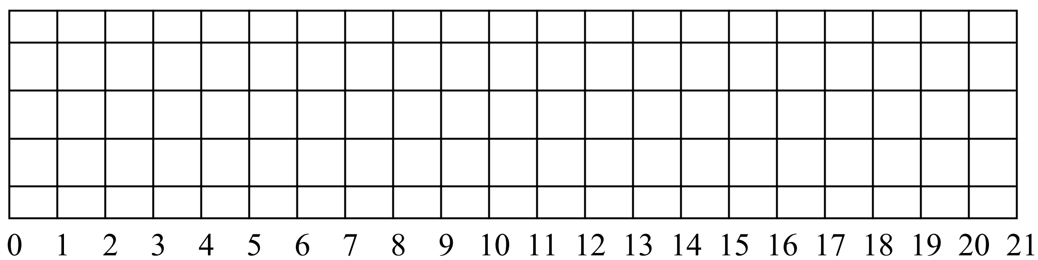


Refer to the drawing above to complete the steps below.

1. Using a scissors or a knife, cut holes in the box where you will mount the diffraction grating and the slit aperture. The hole for the grating should not be larger than the grating; when you attach the grating, it should cover the hole completely.
2. Cut a flap in the box's lid over where you will place the scale grid. This will allow you to open a "skylight" in the box to illuminate the scale grid—with ambient room light or a flashlight—for easy reading.
3. Construct a slit aperture by taping two pieces of thin, opaque card stock to the box, covering the hole you cut. The two cards should be placed edge-to-edge, parallel to each other, and very close together—no more than about 2 mm apart. Note: The slit's long dimension should be oriented vertically, from top to bottom of the box.
4. Tape the diffraction grating over the hole you cut for it. **Note**: Before you tape, make sure that your grating is rotated correctly. When you

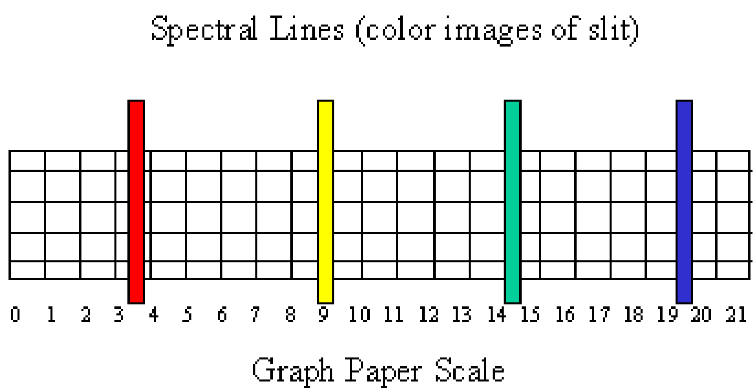
look through the grating at a light source, the two spectra should be to the left and to the right of the vertical slit aperture.

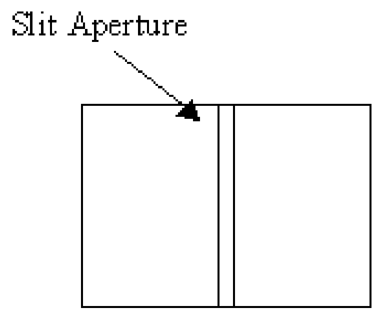
5. Cut out a strip of graph paper (quarter-inch division graph paper will be fine) 3 cm high and about 10 cm long (depending on the size and shape of your box). Cut along the graph paper lines so that the lines are parallel to the cuts.
6. Number the graph paper scale, from left to right, starting with zero. The numbered graph paper strip should look something like this:



7. Cut out a piece of cardboard or stiff card stock about the same size as the graph paper strip.
8. Tape (or glue) the graph paper strip to the cardboard strip.
9. Tape the graph paper scale into the box with its longer dimension horizontal to the box's bottom. You will want to slant the scale, as shown in the drawing, so that when you look at it through the diffraction grating hole, you see it face on, not slanted. **Note**: Before you tape the scale into position, look at a light source through your nearly completed spectroscope. The graph paper scale should fall behind (as a backdrop) one of the two spectra created by the diffraction grating.

When all is done, what you should see when you look into the diffraction grating and point the slit aperture at a fluorescent lamp is something like this:





Activity 3: Observe

If you choose to observe sunlight with your spectroscope, first repeat the following sentence one thousand times:

I will not look directly at the Sun…

It is very important that you do not look directly at the Sun, not with a telescope, not with a camera, not with a pair of binoculars, and not with your spectroscope. The Sun's light is very bright, and can damage your eyes. If you want to look at the spectrum of sunlight, try looking at a piece of white paper onto which the Sun is shining. The result is not as bright, but the spectrum is the same.

Step by Step

Observing List

- ■ Fluorescent lamp
- ■ Incandescent lamp
- ■ Red LED (light emitting diode)
- ■ Green LED
- ■ Yellow LED
- ■ A white area on a television screen
- ■ Yellow neon sign
- ■ Red neon sign
- ■ Green neon sign
- ■ Light source of your own choice

1. Choose a light source from the observing list above.
2. Look at the light source through your spectroscope, pointing the slit aperture at the light source and hunting around until you see its spectrum over the graph paper scale (you may need to sweep your spectroscope from side to side to find the spectrum).
3. Record the spectrum you see using the data collection sheet. On the data collection sheet you will sketch the spectrum <u>and</u> record the

numeric scale positions of each spectral line (or each transition between different colors, for a continuum spectrum).

If a spectral line falls between two numbers on the scale, estimate the fraction of the distance between the integer numbers on the scale. For example, if the line is about halfway between 3 and 4, record a spectral position of 3.5. If it is three quarters of the way between them, record 3.75.

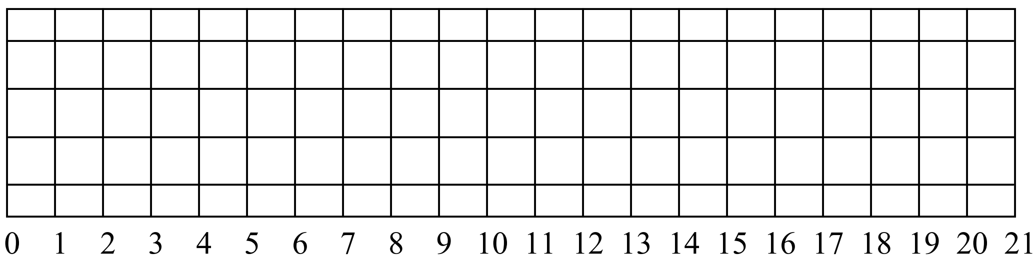
Note: if the spectrum you see is a continuum, record the positions *between* the distinct color bands. For example, for the blue band in a continuum spectrum, record the position where "blue begins" and also where "blue ends" (where blue ends, by the way, should also be where green begins).

4. For each data log sheet on which you record a spectrum, be sure to include the date, your name (observer), and the light source being observed.
5. Repeat the observing process for different light sources (try to observe as many of the light sources on the observing list as possible). Use a new data log sheet for each source you observe.

Data Sheet

Record a spectrum by drawing what you see on your spectroscope scale in the scale graph and by recording the line and band information in the columns at the bottom of the table.

Date	Time	Observer	Object



Is the light source a:

- ■ Continuum spectrum?
- ■ Emission spectrum?
- ■ A combination of continuum and emission spectra?

Line Color *	Scale Position	Brightness **

* If this is a continuum spectrum, then indicate each band of color by writing “Blue Band” or “Red Band” or “Yellow Band,” etc. In the Scale Position column, record both the beginning and end positions of that color band (for example, writing “2.5 to 4.1” would show the beginning (2.5) and end (4.1) positions for the given color band.

** Record the line or band brightness *qualitatively*. For example, “faint” or “bright” or “medium.”

Activity 4: Classify the Spectra

At this point you have become familiar with a diffraction grating, constructed a spectroscope, observed light sources with the spectroscope, and recorded spectra. In this activity, you will summarize your observations by classifying and comparing your spectra.

Step by Step

1. Collect all of your data log sheets and staple them together.
2. Number each page with a unique number (1, 2, 3, …); you will refer to your spectra by these numbers.
3. Using the table below, list each of your spectra and classify them:

Spectrum Number	Light Source	Type of Spectrum *	Brightest Color (line or band)	Number of Lines (if an emission spectrum)

* Continuum, Emission, Combination

Examine your spectra carefully. Can you find any emission lines that are at the same scale position as those in another spectrum? If so, record your findings below:

Lessons Learned / Questions / New Ideas:

1. As you think back on the activity, what are some things that you understand now that you did not know before? What are some questions you have?
2. What questions do you have?
3. Can you find a way to use your spectroscope to investigate one of your questions?

Additional Activities

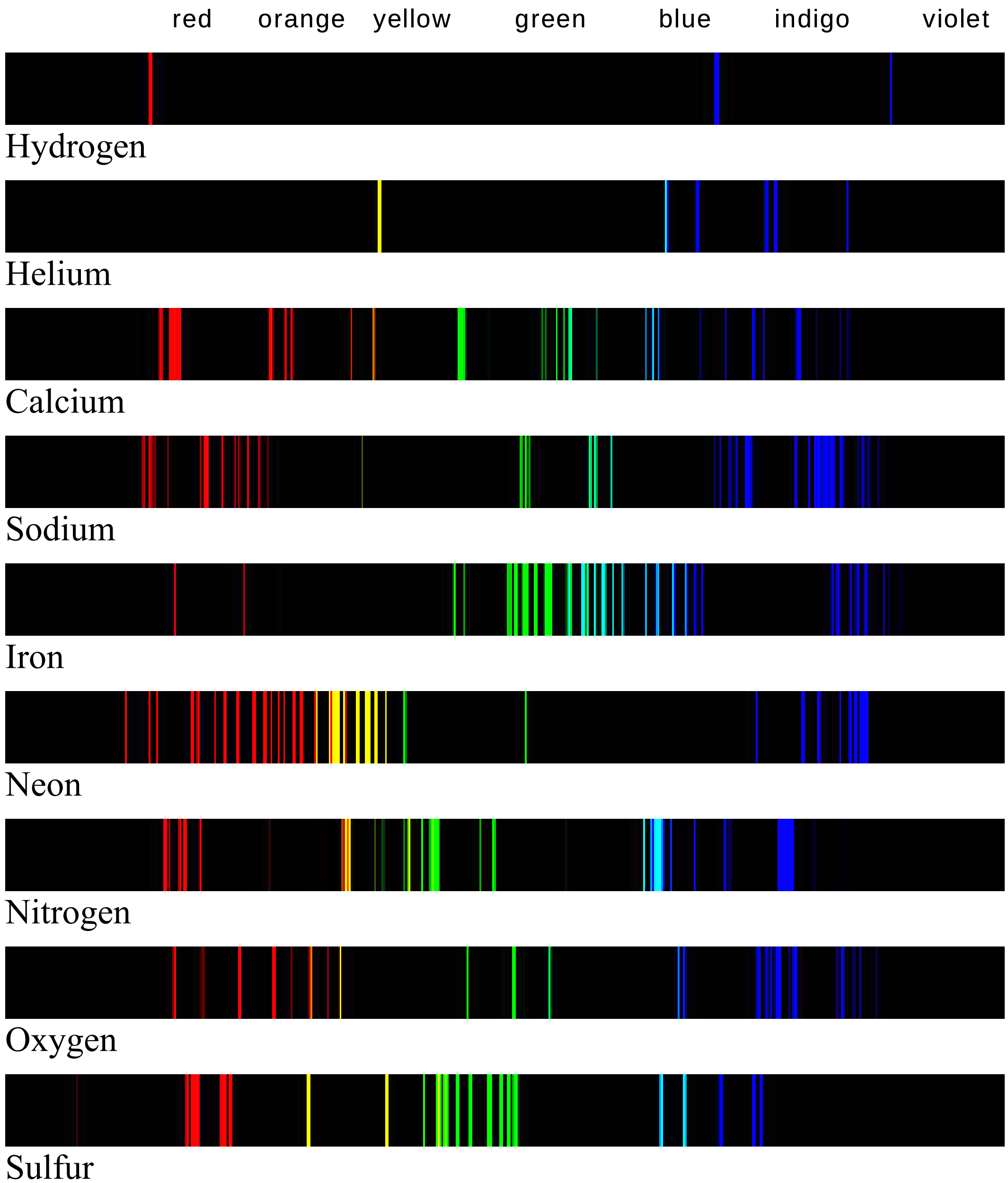
Identify Gases With Your Spectroscope

Materials Needed

- A gas emission lamp with tubes of various gases (such as hydrogen, helium, sodium, calcium, iron, etc.)
- Your spectroscope
- Pictures of sample spectra

On the next page are several spectra of some common gases as they would be seen through a slit-aperture spectroscope such as the one you built.

Sample Spectra



Step by Step

1. Your teacher will select an emission tube containing an unknown gas.
2. Observe the tube with your spectroscope and try to identify the type of gas. Note: Your teacher may have chosen a gas whose spectrum is not included in the color spectrum sheet.
3. Draw the spectrum that you observe using appropriate colors and spacing.
4. Try to identify the spectrum from the given list of color spectra or state if you think it is not present.
5. Record the actual gas in the column provided when you go over the list as a class.

Tube #	Draw the Spectrum	Prediction	Actual

Questions:

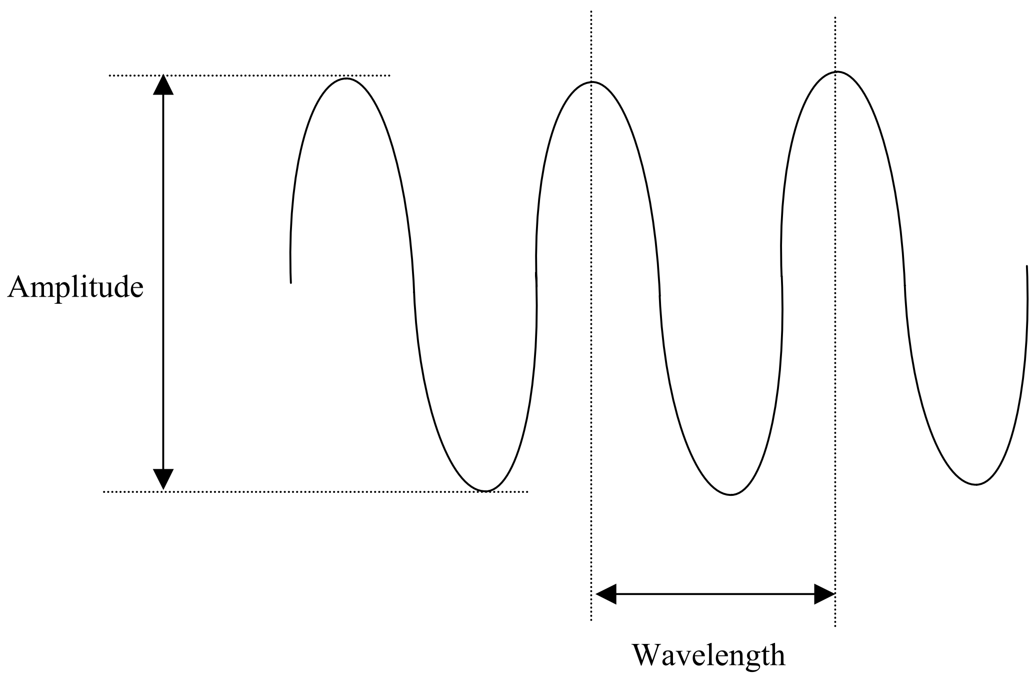
1. How many of your predictions were correct? Give a brief explanation for why you got some, a few, or none.
2. What is the difference between emission spectra and absorption spectra?
3. How is this technology used to identify the composition of stars?

Information for Teachers

Brief Introduction to Electromagnetic Waves

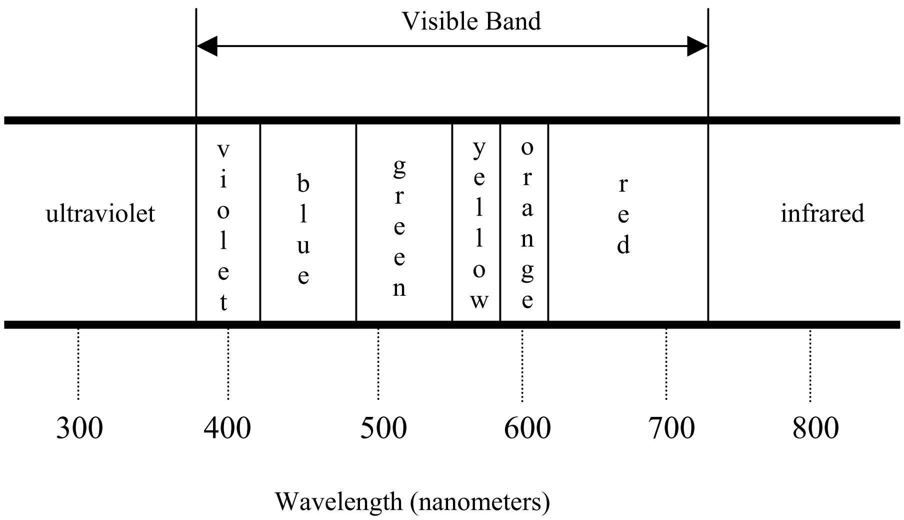
Light is a wave phenomenon: a repeating fluctuation that travels through space. Light waves are similar to sound waves, waves on water, or waves of vibration on a guitar string. However, where sound waves are repeating fluctuations in air (or liquid, or solid objects), light waves are fluctuating, oscillating electric and magnetic fields, which is why light is called an *electromagnetic wave*.

Two properties that we can identify and measure in all waves are *amplitude* and *wavelength*. The amplitude of a wave is a measure of its strength. For waves of water on the ocean, amplitude can be thought of as the height of a wave measured from the deepest point of a trough (the lowest water level, between wave crests) to a neighboring wave crest. The wavelength of an ocean wave is the distance measured horizontally from one wave crest to the next wave crest in a series of waves.



The amplitude of a light wave is a measure of the amount of energy in that wave. The wavelength is the linear distance between one wave and a subsequent wave.

Just as a wave on water may have any of a wide range of wavelengths and amplitudes, so do light waves. The entire range of possible wavelengths of light, from miles to lengths smaller than the nucleus of an atom, is collectively called the *electromagnetic (EM) spectrum*. The portion of the EM spectrum that the human eye is sensitive to is a relatively small portion, ranging from 400 to 700 nanometers, and is called the *visible spectrum*. The allocation of the visible spectrum, along with the neighboring invisible bands called the *ultraviolet* and the *infrared* bands, is shown in the drawing below, along with the corresponding wavelengths, in nanometers.



It is important to note that what the human eye perceives as a specific color – red, for example – is actually a band of different, neighboring wavelengths. Simply seeing the color red with the eye does not identify the light's exact wavelength, just the range that the color belongs to. A spectroscope, however, can enable us to sort out and identify every wavelength, individually.

What is a Spectroscope?

When light enters your eyes, all of the different wavelengths it contains are mixed together. Your eye and brain interpret the mix of wavelengths as a single color. This is why, even though there is a very small number of "basic" colors, we can identify millions of different shades, most of which are blends of many different wavelengths. **A spectroscope is a device that separates light into the different wavelengths it contains.**

What is it used for?

Spectroscopes are used for a number of purposes, but in all cases the information sought is the same: the brightness of each individual wavelength of light coming from a source.

The wavelength composition of light can reveal some important things about the light's source, such as what atoms or molecules are present in the light source. The technique of spectroscopy can therefore reveal what distant objects, such as stars, are made of.

An atom is made up of electrically charged particles: a *positively* charged nucleus and *negatively* charged electrons that orbit the nucleus, bound to it by the attractive electric force between opposite charges.

In the absence of an outside influence, an electron will orbit an atom's nucleus in a stable, unchanging orbit. An outside force (such as a collision with another atom or a photon of light) can give an electron enough energy to "jump" to a higher orbit. The electron may remain in this higher orbit for a time, but will eventually fall back to its lower, "ground state" orbit, in the process releasing energy in the form of a pulse of light: a photon. The wavelength of the photon is determined by the amount of energy released, which in turn is determined by the energy difference between the two different orbits.

Electrons orbit their atoms at specific discrete levels, and cannot orbit at levels between. This phenomenon is called *quantization*. An electron in a given orbit possesses an amount of energy specific to that orbit. The amount of energy in a given orbit, and thus the difference in energy between two given orbits, is also specific to the particular atom, or molecule.

This means that the discrete wavelengths emitted are unique to each atom or molecule, just as a human being's fingerprints or DNA are unique to an individual human being. A spectroscope can reveal all of the different wavelengths present in a given source of light, and so from the spectral data it is possible for us to identify the substance(s) that emitted the light.

What data does it gather?

A spectroscope reveals the brightnesses of the different wavelengths of photons present in a light source. A *slit spectroscope* collects light through a long, narrow slit. When this beam of light is divided and spread out into its different wavelengths, the image formed on the surface the light falls on (a projection screen, photographic film, a CCD chip, an eyeball, etc.) is a row of long, narrow lines, each a different wavelength. The shape of the slit aperture forms the shape of these lines. The brightness of a particular line reveals the brightness of that particular wavelength. The lines are arranged, side-by-side, in the order of their wavelengths. This image is called a *spectrum*.

What is the optical phenomenon that a Spectroscope employs?

There are two basic different types of spectroscopes: *refractive* and *diffractive*. Refractive spectroscopes employ the optical phenomenon of *refraction* to divide light into its different wavelengths, while diffractive spectroscopes use the phenomenon of *diffraction*.

Refraction

In different transparent substances light can travel at different speeds[1]. For example, light travels more slowly through water than through air. If the light wave passes between the two substances at an angle that is not straight on, its direction of travel is changed. This changing of the light's path is called *refraction*. The amount of bending depends on several things, including the types of substances the light is passing between, the angle at which the light strikes the interface between the substances, and the wavelength of the light.

The effect of wavelength on the amount of refraction is what is important in spectroscopy. The shorter the wavelength, the more the light is refracted. Blue light is bent by refraction more than red light, since blue light has a shorter wavelength.

You can see the effects of refraction in the world around you. Rainbows are formed when raindrops or cloud droplets refract sunlight. Sunlight passing from air into the droplet of water is refracted, and a small amount of this is reflected off of the inside surface of the raindrop. The reflected light is refracted a second time when it passes out of the droplet and back into air. This refracted light, coming from billions of raindrops filling a volume of sky, forms the image of the rainbow.

If you look closely, you can often see glints of different colors as light travels through various transparent objects, such as crystal, water or glass.

---

[1] The speed of light traveling through a vacuum is constant, but light traveling through transparent substances is slower and depends on the substance's density and chemical composition.

A refractive spectroscope uses a prism to split light. A prism is a wedge of glass or crystal with flat surfaces. Light is directed through the prism, refracts, and emerges from the prism with the different wavelengths traveling in different directions.

Diffraction

Diffraction is the phenomenon that occurs when waves travel past solid objects, such as when waves traveling on the ocean pass by an island or through an inlet. Instead of moving on in the same direction, the waves are partially bent towards the object, tending to fan out to fill the area behind. Sound waves passing through fluid diffract around solid objects. This is why you can hear a noise around a corner or from behind something: the sound waves diffract, or bend, around the object and arrive at our ears after following a curving path.

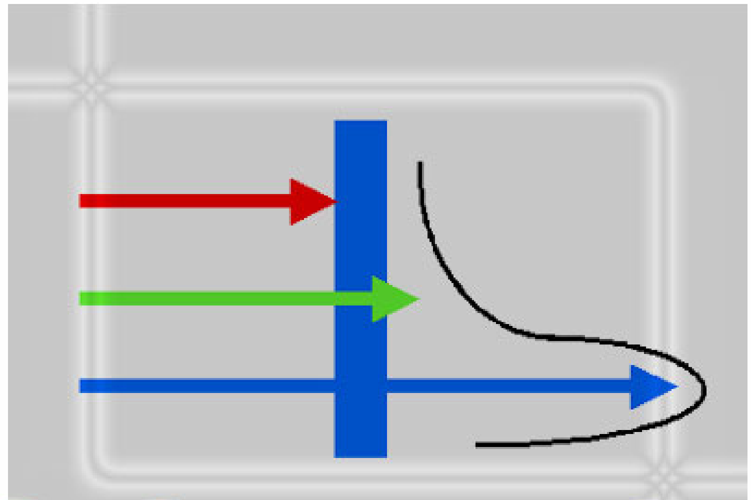
Light is a wave of electromagnetism. Like any wave it experiences diffraction when passing near a solid object. Only the light passing very near the solid object—on the order of distance of the wavelength of the light itself—is diffracted; light waves passing farther away continue to travel undisturbed. So, if you consider a single solid object as the diffractor, only a very small percentage of light passing by is actually deviated.

However, if we consider a surface perforated with many holes, or cut with many slits or grooves, the situation is different. If the holes or the slits in this surface are small then much of the light that passes through them will pass very close to the solid material and will be diffracted.

The wavelength of light determines by what degree it is diffracted. Longer wavelengths are bent (diffracted) more than shorter wavelengths, so red light is more strongly diffracted than blue.

A readily available example of a surface filled with many very tiny holes is a compact disk, a CD. A CD stores music or computer data digitally in the form of many very tiny holes in a silvery (usually aluminum) surface. Look at a light source reflected from the CD's surface and you will see the different colors of light spread out there.

A surface with many slits or grooves etched on it also serves very well to diffract the light passing through or reflecting off of it, as long as the slit widths are small. A very common and inexpensive material for diffracting light is a "diffraction grating," a piece of glass or plastic with thousands of narrow, regularly spaced grooves etched on its surface.



Colorgraphs

See the world in a new light

Solar-B Education and Public Outreach (EPO)

Solar-B is a multinational solar observatory satellite project headed by the Japanese Space Agency (ISAS), in partnership with the United States (NASA) and the United Kingdom (PPARC).

The Solar-B EPO program at Chabot Space & Science Center is funded by a grant from the Lockheed-Martin Solar and Astrophysics Lab (LMSAL) in Palo Alto, California.

The activities and materials in this package were developed for the *Touch the Sun* teacher-training workshop at Chabot Space & Science Center, 10000 Skyline Blvd., Oakland, California 94619.

Colorgraphs

Nuts and Bolts

What Students Will Do

- Learn about color filter bandpass curves.
- Measure the bandpass of various filters.
- Graph the bandpass of various filters.
- Create your own color filter and predict its bandpass curve by analyzing and combining the data from two or more component filters.

Key Concepts

- Most sources of light that we see are made up of many different wavelengths (colors) of light.
- What the human eye and brain perceive as a color (for example, “red”) is usually a range, or band, of different wavelengths of light.
- The human eye and brain blend together different colors of light. What we perceive is the blended result, not necessarily the individual colors present.
- Color filters are pieces of material (plastic, glass) that are transparent to some wavelengths of light and opaque or nearly opaque at other wavelengths.
- Color filters can be used to selectively block out certain colors of light and so emphasize a desired color.
- A color filter can be characterized by a graph of the amount (percentage) of each color that is transmitted versus color of light. The curve produced on this type of graph is called a bandpass curve.

Materials Needed (per working group)

- A diffraction grating
- Two or more color filters, of your choice
- An incandescent light source (a light bulb)
- A copy of the Color Filter Bandpass Data Sheet

Introduction

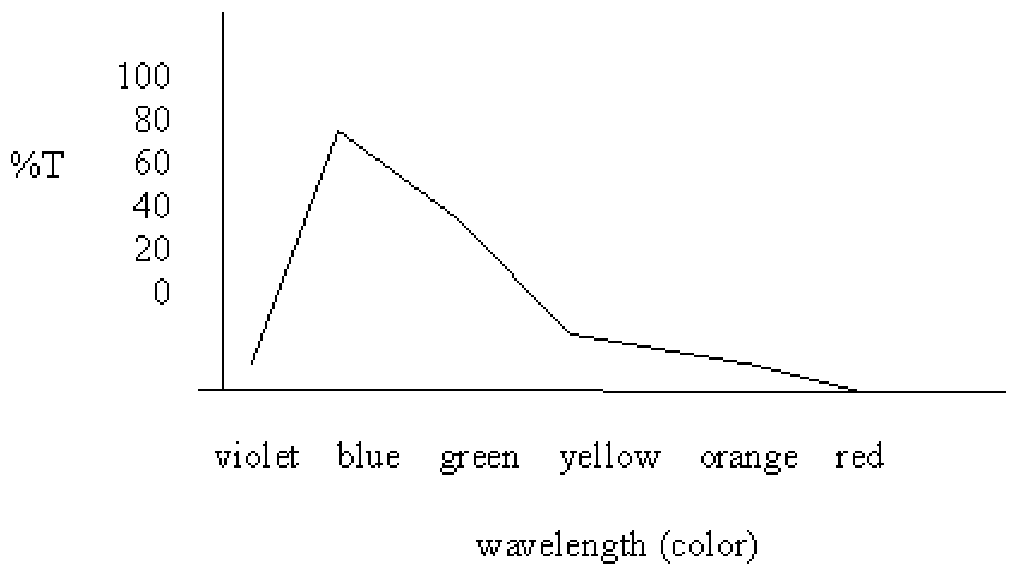
Description

Filter imaging is the method of capturing photographic images through color filters. The color filters are used to block off unwanted wavelengths of light to allow only desired colors of light into the imaging device (camera, eyeball).

In this activity you will explore the properties of color filters, and learn about filter *bandpass*.

The bandpass of a color filter describes how much of each color of light can pass through the filter in question. It's not enough to say that half (50%) of the light striking a filter passes through. The percentage of light that can pass through the filter at every possible wavelength in the spectrum must be known.

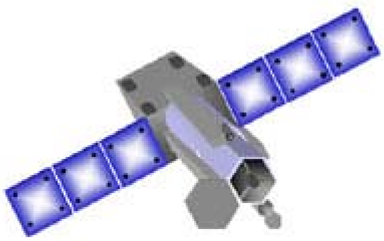
A graph is a great way to express filter bandpass. A graph of *percent transmission* versus *wavelength* will characterize the bandpass of the filter with a curve, which is why this type of graph is called a filter's *bandpass curve*. (Percent transmission for a given wavelength of light is the percent of the light that passes through—or is transmitted—the filter.)



Bandpass Curve Example

Above is a sample bandpass curve that describes a color filter that transmits less than 10% of violet light that strikes it, over 80% of the blue light, less than 60% of the green light, etc. This filter allows more blue light than any other color to pass through it. It also transmits 0% of red light, so no red light should be visible through this filter.

Solar-B Connection



Solar-B will use sophisticated color filters to create images of the Sun from light of very specific wavelength. In this way Solar-B will produce images from light emitted by specific chemical elements, allowing astronomers to determine the distribution and temperature of those materials.

The *bandpass* of filter systems on Solar-B will be very accurately controlled, allowing astronomers to select the exact wavelength or band of wavelengths they want.

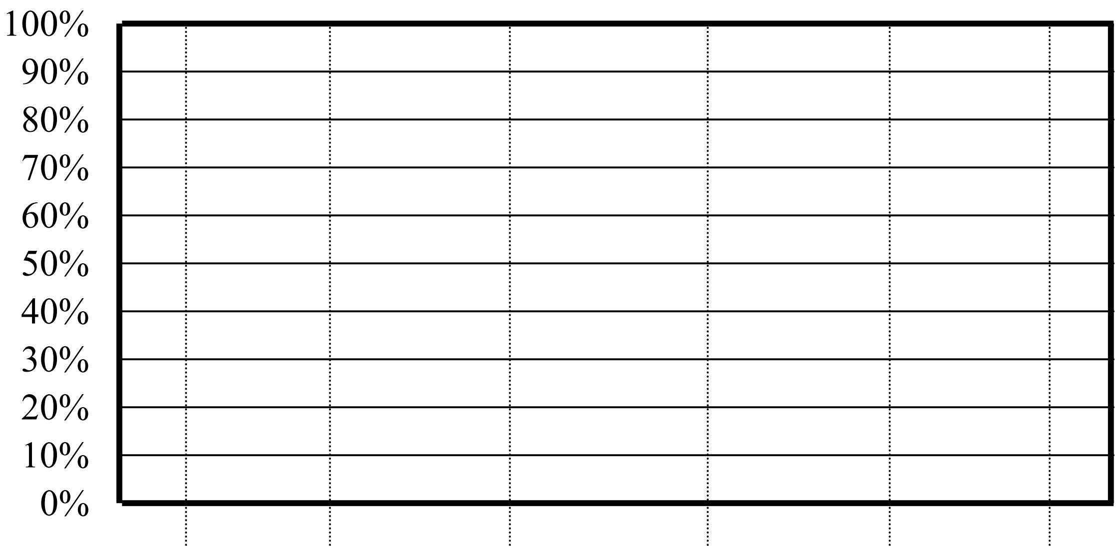
Activity 1: Determine the Bandpass Curve of a Filter

Step by Step

1. Choose a filter that you like. Suggestion: Choose a "dark" filter – that is, a filter that substantially blocks light like a pair of sunglasses does.
2. Hold a diffraction grating up to an incandescent light source and look at the rainbow of colors in its spectrum. The grating splits up and sorts out the different colors contained in the light. You should see all of the colors of the visible spectrum in a continuous smear.
3. Still looking through the diffraction grating, hold the filter up to your eye and look again at the incandescent light's color spectrum (you should be looking through both the grating and the color filter).
4. For each color (violet, blue, green, yellow, orange, and red), compare that color's brightness as seen through the filter to its brightness without the filter. Rate the relative brightness on a scale of 0% to 100%, where 0% means that no light of that color passes through the filter and a rating of 100% means that all of that color passes through the filter. For example, if a color looks about half as bright through the filter than it does without the filter, give it a rating of 50%. Use the data sheet on the next page to record and graph these numbers.
5. On the graph provided on the data sheet, plot each number you measure.
6. Connect the data points you have drawn on the graph.

Color Filter Bandpass Data Sheet

Filter Color:	
Filter Name/Number:	



Graph Area

violet	blue	green	yellow	orange	red

Data Logging Area

You are provided with several rows in the Data Logging Area above so that you may record the bandpass of more than one color filter on this sheet. In activities where you do record more than one filter, make sure that their graphs are easily distinguished from each other (user different symbols for the plotted points of each curve and label each row in the Data Logging Area with the appropriate plot symbol.

Activity 2: Design Your Own Color Filter

In this activity, you will design your own color filter. You will select and test two or more component filters, record their spectral bandpass curves, and from that data you will try to predict what the spectral bandpass curves of the combined filters will be.

Step By Step

1. Choose 2 or more different color filters.
2. Perform *Activity 1: Determine the Bandpass Curve of a Filter* for each of the filters you have chosen. You will graph the bandpass for each filter. You should use one data sheet to record data for all of the filters, using different colored pens or different symbols for each set of filter data so that you can tell the data points and plotted curves apart. Make sure to include a legend that shows which symbol/color on the graph corresponds to which filter.
3. Next, *multiply the filter curves*. That is, for each color, multiply together the percentage transmissions you obtained for each filter. Write down the resulting number for each color of light. Note: Remember that when multiplying percentages, the percentages must be expressed as a decimal number between 0 and 1 (for example, 50% = 0.5, 100% = 1.0, etc.). Afterward, convert the results back to percentage form. For example, 30% x 40% = 0.3 x 0.4 = 0.12 = 12%.
4. Plot on the graph the new percentages you have calculated. You may plot them on the same graph as the original data points, or on a new copy of the graph form. This new curve is your *predicted* bandpass curve for the *combined* filters.
5. Next, put your chosen filters together and once again perform *Activity 1: Determine the Bandpass Curve of a Filter*, but on the combined filters (looking through all of the filters).
6. Compare the filter bandpass curve you obtained through observation in Step 5 to the predicted bandpass curve you calculated and plotted in Steps 3 and 4. How closely does the prediction match the observation? What do you think might account for any differences?

What Have You Done?

The data you gathered through observation is the percentage of light of different colors that the filter *transmits*. The rest of the light—that which was not allowed to pass through the filter—was *absorbed* by the filter.

If one filter transmits only half (50%) of the blue light striking it, and a second filter also passes half of the blue light, then the two filters together transmit only <u>one quarter</u> of the blue light. The first filter passes half of the blue light, then the second filter passes half of the *remaining* light, and half of a half is a quarter.

Putting it mathematically, that's **50% x 50% = 0.5 x 0.5 = 0.25 = 25%.**

Using a more realistic example, if you rated the red-pass of your first filter to be 70% and the red-pass of your second filter to be 30%, then the combined red-pass of the two filters is:

70% x 30% = 0.7 x 0.3 = 0.21 = 21%

Lessons Learned / Questions / New Ideas

1. As you think back on this activity, what was most surprising?
2. What are three things you learned that you did not know before?
3. What are three questions you have?
4. Optional: Design an experiment to test one of your questions that uses your new understandings of filters and how they work.

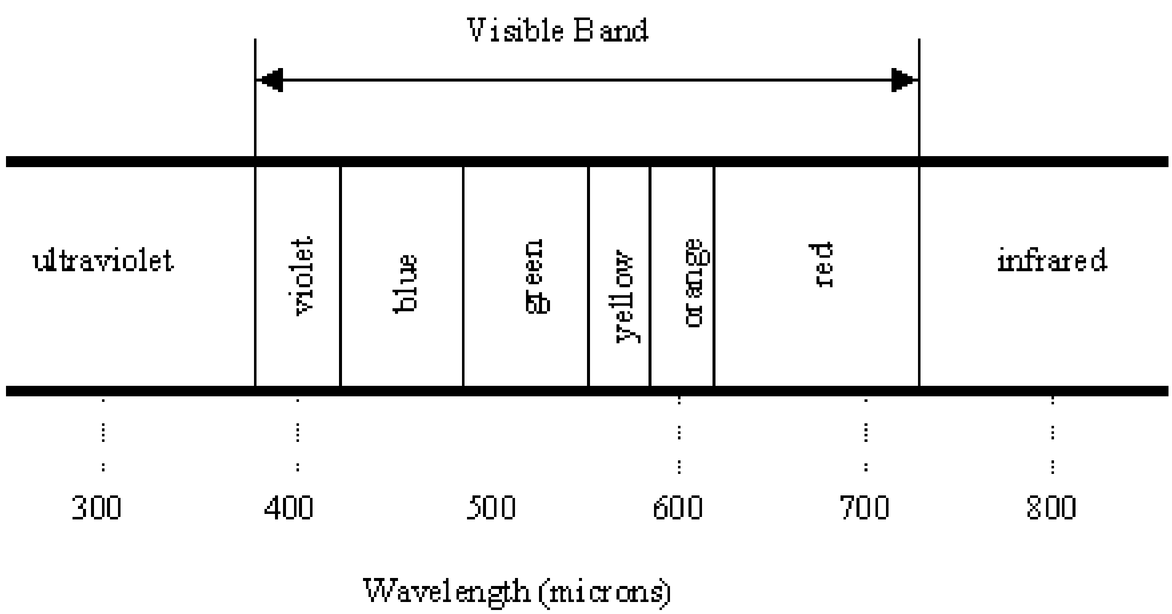
Information for Teachers

Color Filters

A color filter is a transparent material that allows some wavelengths of light to pass through it while blocking some or all light of other wavelengths. Colored gemstones, stained glass, blue-blocker sunglasses, and Coca-Cola bottles all possess the characteristic of color filtering.

Color filters are characterized by which wavelengths they allow to pass through, or *transmit*. You can say that a "blue filter" transmits "blue" light, but there is actually a range of wavelengths of light that our human eyes perceive as blue. So the question becomes, for a given blue filter, which "blue" wavelengths are transmitted and which, if any, are not?

The spectrum of visible light is shown below.



Visible Band of Electromagnetic Spectrum

Each color that is distinguished by our eyes is actually a range, or *band*, of many different wavelengths. It is useful to refer to the "red" band as all wavelengths that our eyes perceive as red. You can refer to the "visible band" as all wavelengths that our eyes can detect (the visible spectrum).

Bandpass

What ranges of wavelengths a given filter transmits—in other words, what *band* it allows to *pass*—is called that filter's *bandpass*. Color filters that transmit only a very small range of wavelengths are called *narrowband* filters, while those that transmit a relatively large range are called *broadband* filters. The color filters that you will use are very likely broadband filters, as narrowband filters tend to be more expensive.

Bandpass Curves

The bandpass characteristic of a given color filter is usually presented in the form of a graph of *percent transmission* versus *wavelength*. The percent transmission is the percent of the total light entering the filter that actually passes out the other side (is transmitted).

Color Filter Imaging

Color filtering has been performed since the invention of photography. A *color filter imager* is simply a camera with a color filter attached to the lens.

Color filter imaging was, and still is, practiced in astronomy with *black and white* film photography and CCD imagery. Light from a celestial object is sent through a color filter and the image is recorded on the black and white medium (film or CCD). A series of similar black and white (or "gray scale") images are recorded, each taken through a different color filter, and the relative brightnesses of the images are compared. The brightest recorded image then corresponds to the predominant color of light coming from the celestial object. The reason that this method is still used is that gray scale image recording systems tend to be more sensitive to faint light sources than do color recording systems, and most celestial objects of interest are very faint.

The usual reason for using color filters when creating an image (a photograph, for example) is to emphasize certain colors in the photographic subject by reducing or eliminating other colors.

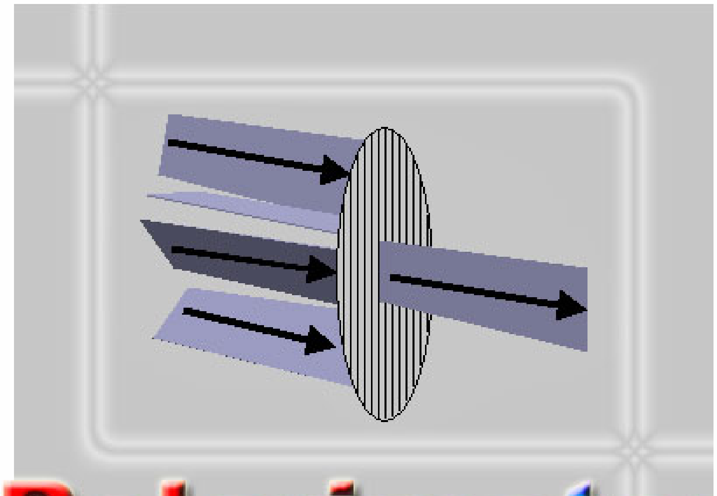
Astronomers use color filtering for a number of reasons:

- The hottest stars emit more light in the blue end of the visible spectrum than in other wavelengths, while the coolest stars emit more red light than other colors. By comparing the brightnesses of stars at different colors, the temperature of the star can be measured.
- By blocking wavelengths of light that typically come from our atmosphere (for example, city light reflecting back from the sky), clearer images of stars and other celestial objects can be taken.

- By using a filter that transmits light characteristic to a particular substance, the amount and distribution of that substance can be appraised.

Making Your Own Filter

Two or more color filters can be combined to produce a customized filter with its own bandpass characteristics. For example, if one filter blocks red, yellow, and orange, and another filter blocks yellow and green, then putting them together will produce a filter that blocks all of those colors, allowing only blue and violet to pass. Adding a third filter that blocks violet will produce a "blue" filter, one that is transparent to blue light and opaque or nearly opaque to all other colors.



Polarimeter

Do NOT use this device to measure a polar bear!

Solar-B Education and Public Outreach (EPO)

Solar-B is a multinational solar observatory satellite project headed by the Japanese Space Agency (ISAS), in partnership with the United States (NASA) and the United Kingdom (PPARC).

The Solar-B EPO program at Chabot Space & Science Center is funded by a grant from the Lockheed-Martin Solar and Astrophysics Lab (LMSAL) in Palo Alto, California.

The activities and materials in this package were developed for the *Touch the Sun* teacher-training workshop at Chabot Space & Science Center, 10000 Skyline Blvd., Oakland, California 94619.

Polarimeter

Nuts and Bolts

What Students Will Do

- Use a polarizing filter to build and calibrate a simple polarimeter.
- Use your polarimeter to find sources of *polarized light*.
- Measure the *angle of polarization* of polarized light sources and attempt to measure the *strength of polarization*.

Key Concepts

- Light is a wave of electromagnetism.
- Polarization is a property of light, just as wavelength (color) and amplitude (brightness) are properties of light.
- The electric field of a light wave oscillates back and forth in space within a geometric plane.
- The directional property of the alignment of a light wave's electric field is called polarization.
- A given source of light typically emits a great number of photons, each of which may be polarized in any given direction.
- A source of light that contains more light waves that are polarized in a specific direction than in any other is called a polarized light source.
- Light can become polarized for several reasons, including reflection from a surface, scattering in a gas or transparent solid, stimulated emission (such as in a laser), or by the presence of a strong magnetic field at the light's source.
- A polarizing filter is a material that allows light waves polarized in a certain direction to pass, but not light waves polarized in other directions.
- A polarizing filter can be used to determine how much and in what direction a given light source is polarized.

Materials Needed

- Polarizing filters
- A cardboard tube (toilet paper tube is excellent)
- A flat piece of cardboard

- Scissors/knife
- Tape
- Protractor
- Marking pen

Introduction

Description

Polarization is a property of light waves, just as wavelength (color) and amplitude (strength) are properties of light. Color and brightness are properties of light that we are all familiar with. Polarization is a property of light that is not as well known, though you may have encountered its effects before without realizing it.

If you have every looked through a pair of Polaroid sunglasses and rotated them while looking at the sky, you have not only experienced the effects of polarization, but have also made a polarimetric measurement!

Light waves (more specifically, the electric and magnetic fields that are light) oscillate back-and-forth as they move, not unlike how a wave on the ocean moves up and down as it travels horizontally across the surface.

The back-and-forth motion takes place within a geometric plane. This plane is called the *plane of polarization*. The plane of polarization is always parallel to the direction of travel of a light wave.

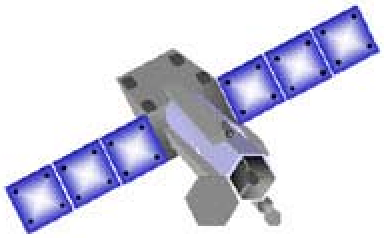
A *polarimeter* uses a *polarizing filter* to measure the direction of the plane of polarization of light.

The polarizing filter is a transparent material that contains many long, string-like molecules that have all been stretched and aligned in the same direction. Depending on the direction of a light wave's plane of polarization as it passes through a polarizing filter, it can pass through the filter easily, with difficulty, or not at all.

A polarizing filter's *axis of polarization* is the direction in which a light wave's plane of polarization must be oriented in order for it to pass through the filter with the greatest ease.

When you look through a polarizing filter, only the light whose planes of polarization are aligned with the filter's axis of polarization pass through and reach your eye. If you know the direction of the filter's axis of polarization, then know the direction of polarization of the light that you see through the filter: they are the same direction.

Solar-B Connection



Strong magnetic fields on and near the surface of the Sun cause polarization in light emitted by atoms on the Sun's visible surface (its photosphere) and in its atmosphere (chromosphere, transition region, corona). Observations of the Sun with a polarimeter can reveal the strength and structure of magnetic fields emanating from beneath the Sun's surface and permeating the various levels of the solar atmosphere. Such observations are one of Solar B's primary goals for studying the life cycles of solar magnetic fields.

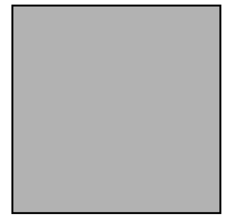
Activity 1: Polarizer Play

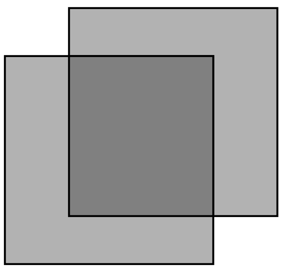
For this activity, you will need 2 polarizing filters.

Step by Step

1. Hold a polarizing filter 1 or 2 feet from your face and look through it. What do you notice?

   You may notice that the polarizing filter appears slightly dark. This is because some of the light passing through the filter has been blocked, like through sunglasses or tinted glass.

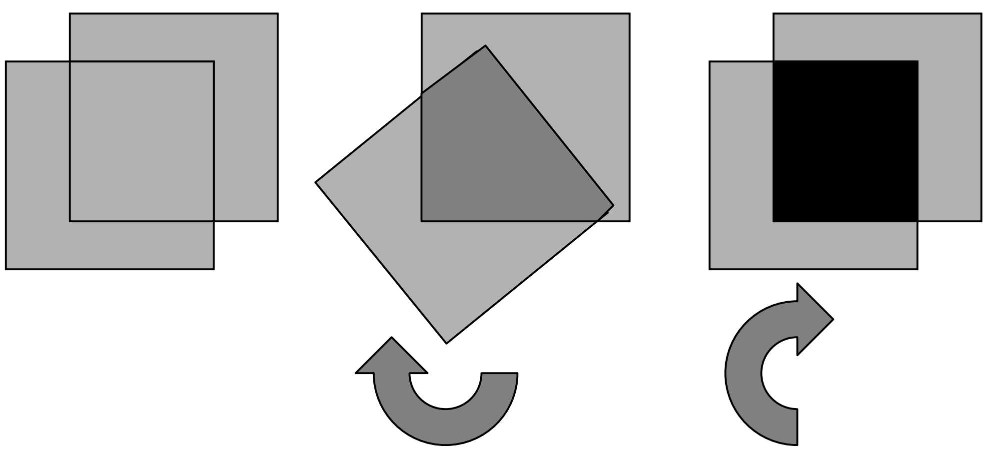




2. Still holding the first polarizing filter a foot or two from your face, place a second polarizing filter in front of your eye so that now you are looking through both filters at the same time. What do you notice?

   You may notice that when looking through both filters things appear even darker. So far things make sense.

3. Now, rotate the second polarizing filter (the one in front of you eye) in one direction or the other. What do you notice now?



You should see that by rotating one of the filters, the degree of darkness seen through both changes. You can change the amount of light filtered by both polarizing filters from light to completely dark.

What is Happening?

Like sunglasses, tinted glass, or color filters, polarizing filters block off some of the light passing through them. With "gray" tinted glass or sunglasses, some of the light of every color is being blocked. With color filters, certain colors of light are being blocked (sometimes completely) while other colors are allowed to pass.

A polarizing filter allows light polarized in certain directions to pass, and blocks light polarized in other directions. The direction of polarization of a particular light wave is the direction that the light's electric field "vibrates" back and forth.

To visualize how this works, think of a comb and a strip of ribbon. The ribbon can be pulled between the teeth of the comb easily if its wide direction is parallel to the comb's teeth. The ribbon, however, cannot be pulled through the comb if its wide direction is perpendicular to the teeth.

Think of a polarizing filter as a sort of comb for light waves, with rows and rows of parallel teeth. The direction that these "comb teeth" are oriented is called the filter's *axis of polarization*. The direction that light's electric field vibrates, or wiggles, back and forth in would be the wide direction of the ribbon.

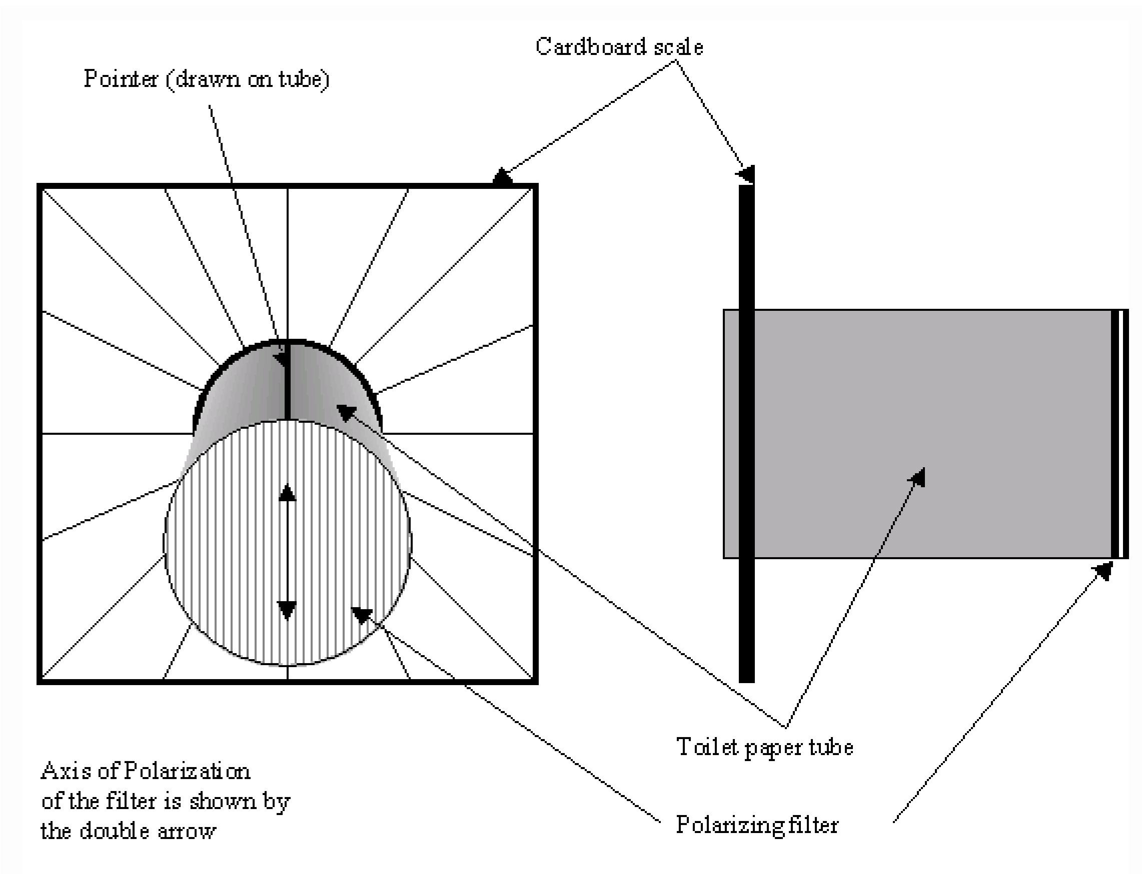
What is happening in the activity you just did is this. Without any polarizing filters, the light shining into your eye is made of many, many light waves whose directions of polarization are pointing in every direction. When you place one polarizing filter before your eye, the light whose polarization is perpendicular to the filter's axis of polarization are blocked, while those parallel to it pass through. Things look a bit darker through one filter because some of the light has been blocked.

The light reaching your eye after passing through the filter are all polarized in the same direction (more or less), so when you place a second polarizing filter in the path of the light, the filtering becomes much more drastic. When the second filter's axis of polarization is parallel to the light's polarization, most of the light gets through. When the filter is rotated 90 degrees so that its axis of polarization is perpendicular to the light's polarization, all of the light is blocked.

Activity 2: Build a Polarimeter

Overview

A *polarimeter* is an instrument for measuring the direction and strength of the polarization of light. The *direction of polarization* of light is the rotational direction, perpendicular to the direction the light is traveling through space, that the majority of light waves are oriented. The *strength of polarization* is how much (what percentage) of the light is oriented in the direction of polarization.



Simple Polarimeter

Here is a drawing of a simple polarimeter that you can build. If you have a better design in mind, follow <u>your</u> design, by all means!

A cardboard toilet paper tube is used to hold the polarizing filter at one end. The other end of the tube is inserted into a hole cut from a cardboard square, which is marked with lines indicating angular units (the lines radiating from the central hole). A line drawn on the tube indicates the direction of the axis of polarization of the filter.

Step by Step

Part 1

1. Cut a toilet paper tube to a length of about 5 centimeters.
2. Use the end of the tube to trace a circle on the polarizing filter.
3. Cut out the circle of filter.
4. Tape the circle of filter material to one end of the toilet paper tube. Be careful not to cover up much of the filter's surface. You must be able to look through the filter without looking through any tape.
5. Find a shiny surface (like a piece of glass) and a light source (an incandescent bulb, sunlight, a fluorescent tube).
6. Set the glass down on a flat, horizontal surface (like the floor or a tabletop).
7. Position yourself so that you can see the light source reflected from the surface.
8. Place the toilet paper tube with its polarizing filter to your eye and look at the reflected light through it.
9. Rotate the filter. As you rotate the filter, you should see the reflected light grow brighter and fainter.
10. Rotate the filter until the reflected light is <u>faintest</u>.
11. Still holding the filter so that the reflected light is <u>faintest</u>, use a marking pen to mark the toilet paper tube at the exact top and bottom of the filter.
12. For each of the two marks you made, draw a straight line (using a ruler) down the side of the toilet paper tube starting from the mark. The line should run straight down the side of the tube, <u>not</u> wind around it.

Part 2

13. Using a drawing compass, draw a circle on a piece of cardboard. The circle should be about 10 centimeters in diameter. Make sure to mark the center of the circle, where the compass' point was stuck.
14. Cut out the circle (keeping the circle, not the border).
15. Place a protractor on the disk so that the protractor's center point is at the center of the cardboard circle. Along the protractor's scale, mark off a point every 10 degrees, from 0 to 180 degrees, on <u>half</u> of the

circle. Make sure your marks are easy to see, and labeled (0, 10, 20…180).

16. Using a ruler, carefully draw lines through each angle mark and the disk's center, so that all of the lines intersect at that center.
17. Label the angular units along <u>half</u> of the circle, from 0 to 180 degrees.
18. Mark the zero degree direction with the word "up." This will be the direction on the dial that you hold pointing up when you make measurements later on.

Part 3

19. Again using the toilet paper tube, trace a circle on the cardboard disk. This circle's center should be at the disk's center.
20. Cut out the smaller circle from the center of the disk, discarding the smaller circle and keeping the larger disk.
21. Insert the toilet paper tube into the small hole you have cut. The tube should fit snuggly enough in the cut hole so that it won't fall out, but you should also be able to rotate the tube in the hole.

You are finished!

Activity 3: Observe

Repeat the following sentence one thousand times:

I will not look directly at the Sun!

It is very important that you do not look directly at the Sun, not with a telescope, not with a camera, not with a pair of binoculars, and not with your polarimeter. Though the Sun is a source of light, it is very bright and can damage your eyes, possibly permanently. Light from the Sun does possess the property of being somewhat polarized, but you will not be able to detect that polarization with your polarimeter; it is too weakly polarized. Leave that sort of measurement to a spacecraft like Solar-B….

There are at least two things that you need to record to make a useful observation. One is the *polarization angle* (or *direction of polarization*) of the light from a given source. The other is the *strength of polarization* of the light—that is, how much of the light in the beam is polarized.

Note that in many cases, you will view a scene through your polarimeter that contains several different sources of light (for example, the scene may include a lamp bulb, the lamp itself, and the background scenery), all of which may have different degrees of polarization. Though you should view and draw the whole scene for context, you should select specific, singular sources of light as your subject of observation. So, if you view the blue sky and it also contains the Moon and some clouds, your subject of measurement should be the blue sky only.

Step by Step

1. Select a source of light to observe (this could be a source of emitted light, like a light bulb, a neon sign, swamp gas, or a television screen, or it could be a source of reflected light, like a window, a mirror, the blue sky, or a cloud).
2. Sketch a picture of the object/light you are observing. This picture should not only include the source of light you are interested in, but the surrounding objects in the scene. This will help you figure out the orientation of the light source with respect to your polarimeter, later on.

3. Hold your polarimeter up to the light source and make sure that the mark for zero degrees (which you labeled “up”) is pointing up, at the top of the dial.
4. View the light source through the polarimeter.
5. Rotate the filter (by rotating the toilet paper tube) to see if the brightness of the light source changes. Rotate the filter fully around before you decide whether or not you see any changes in brightness. Make sure that the part of the dial marked “up” remains pointing up.
6. If you do not see a change in brightness, you may conclude that the light source is not polarized. Record this fact on your data sheet by writing “unpolarized light.”
7. If you do see a change in brightness, rotate the tube until the light source is at its brightest. You may need to turn the filter back and forth a few times to figure out exactly what filter position gives the most brightness.
8. Read the angle on the dial where the line on the toilet paper tube points. This is the angle of polarization, 0 (and 180) degrees being vertical polarization and 90 degrees being horizontal polarization (assuming the “up” mark on your dial is pointing up). Record the angle under the “Maximum Angle” column.
9. Next, turn the filter tube until the polarized light source appears faintest. Record this angle as the “Minimum Angle.”
10. Using a scale of 0 to 10, rate the brightness of the light when the filter is rotated to make it faintest. A “0” means you see none of the polarized light through the filter and a “10” means you see all of it (that is, its just as bright as when the filter is rotated to the brightest position—so a rating of “10” really means that the light source is not polarized). Record this number under the “Brightness at Min.” column.

Data Log Sheet

Date	Time	Observer	Object/Source	
Drawing of Object	**Maximum Angle**	**Minimum Angle**	**Brightness at Min. ***	**% Polarization**
Date	**Time**	**Observer**	**Object/Source**	
Drawing of Object	**Maximum Angle**	**Minimum Angle**	**Brightness at Min. ***	**% Polarization**
Date	**Time**	**Observer**	**Object/Source**	
Drawing of Object	**Maximum Angle**	**Minimum Angle**	**Brightness at Min. ***	**% Polarization**
Date	**Time**	**Observer**	**Object/Source**	
Drawing of Object	**Maximum Angle**	**Minimum Angle**	**Brightness at Min. ***	**% Polarization**

* This is the Brightness at Minimum compared to the Brightness at Maximum, expressed on a scale of 0 to 10, where 0 means that none of the polarized light is getting through the filter and a 10 means that all of it does.

Activity 4: Analyze the Data

The reason for recording this brightness at minimum value is to try to measure the light source's *percentage of polarization*. This is a measure of how much of the light from the source is polarized in the direction of polarization. The percentage of polarization for a light source such as a laser beam is practically 100%, as just about all of the laser light is polarized in the same direction. Unpolarized light has 0% polarization. Most polarized light sources in nature fall somewhere between these two extremes.

To calculate percent polarization, use the brightness at minimum compared to brightness at maximum. Simply divide the Brightness at Minimum by the maximum value of the scale you are using (in this case, 10). Multiply the result by 100 to get a percent. For example, if you rated the minimum brightness of the polarized light of a source with a 4, then the percent polarization is:

$$(4 / 10) * 100 = 40\%$$

Enter your results on the data log sheet under "% Polarization."

Based on your observations, make three lists below: 1) Sources of strongly polarized light (greater than 50% polarized), 2) Sources of weakly polarized light (equal to or less than 50% polarized), and 3) Unpolarized sources.

Strongly Polarized (> 50%)	Weakly Polarized (≤ 50%)	Unpolarized (0 %)

Lessons Learned / Questions / New Ideas

Now that you have experienced the process of building, using, and analyzing data from a simple polarimeter, write down all of the things that you would do differently (if anything) if you were to build another.

1. What would you do to improve the design of your polarimeter (its size, dimensions, measurement surface)?
2. What would you do to improve the construction of your polarimeter (the materials used, the methods of attaching everything together)?
3. What would you do to improve the way in which you use the polarimeter to collect data from the Sun?
4. How do you think any of these changes would improve the ease of use and accuracy of the data collected?
5. What questions do you have?
6. What new understandings/ideas do you have as a result of building a polarimeter, collecting and analyzing data?

Information for Teachers

What is Polarized Light?

Polarization is a property of light waves, just as wavelength (color) and amplitude (strength) are properties of light. Color and brightness are properties of light that we are all familiar with. Polarization is a property of light that is not as well known.

A single photon of light is a wave of electromagnetism: an electric and magnetic field oscillating side-to-side with respect to the direction of travel of the photon. Analogously, in a wave of water on the ocean the water is physically moving up and down, but the energy of the wave propagates horizontally along the ocean’s surface.

For a photon (an electromagnetic wave) the plane in which that the electric field oscillates is called the *plane of polarization*, or the *direction of polarization*, of the photon. The electric field oscillates back and forth within that plane, perpendicular to the direction that the photon is traveling through space.

Most of the sources of light in nature emit “unpolarized” light. What this means is that for the trillions of photons emitted by the source, the direction of polarization of each individual photon is random: there are just as many photons whose electric fields oscillate in one direction as there are in any other.

Some sources of light are “polarized” to some degree. That is, there is a certain direction in which a majority of the photons’ planes of polarization are aligned.

There are a number of reasons why light becomes polarized, both in nature and in the realm of human technology. Light reflecting from a shiny surface, such as glass or water, tends to be polarized. Light from the sky (sunlight scattered by air molecules in Earth’s atmosphere) is somewhat polarized—more strongly when coming from certain directions. Laser light is very highly polarized: most of the photon’s electric fields in a laser beam are aligned in a common direction.

Strong magnetic fields on and near the surface of the Sun cause polarization in light emitted by atoms in the solar atmosphere. Observations of the Sun with a polarimeter can reveal the strength and structure of magnetic fields emanating from beneath the Sun’s surface and permeating the various levels of the solar atmosphere. Such observations are one of Solar B's primary goals.

What is a Polarimeter?

A polarimeter measures the brightness of light polarized in a particular direction. If the light source is unpolarized (with as many photons polarized in one direction as any other), then the polarimeter will measure the same brightness of light for every polarization direction.

If the light is polarized—if there is a direction in which a majority of the photons are polarized—then the polarimeter will measure the greatest brightness in that direction, and lesser brightness in all other directions.

What is the Optical Phenomenon That a Polarimeter Employs?

A polarizing filter is a transparent piece of material (plastic or glass usually) that contains many long, electrically conductive molecule chains, all lined up in about the same direction. If photon passes through the filter with its electric field perpendicular to the direction that the long chain molecules are aligned, it will usually pass through the transparent material unperturbed. However, if the wave's plane of polarization is parallel to the chains, the oscillating electric field will interact with electrons in the chains, causing them to move up and down the chains in a weak, alternating electrical current. The current creates its own electric field, and the interaction between that field and the photon's electric field cause the photon to be absorbed, and it will not pass out of the filter.

Shoebox Satellite

Heroically engineer
a spacecraft
that will enable
Ice and Eggs
to travel safely in space

Solar-B Education and Public Outreach (EPO)

Solar-B is a multinational solar observatory satellite project headed by the Japanese Space Agency (ISAS), in partnership with the United States (NASA) and the United Kingdom (PPARC).

The Solar-B EPO program at Chabot Space & Science Center is funded by a grant from the Lockheed-Martin Solar and Astrophysics Lab (LMSAL) in Palo Alto, California.

The activities and materials in this package were developed for the *Touch the Sun* teacher-training workshop at Chabot Space & Science Center, 10000 Skyline Blvd., Oakland, California 94619.

Shoebox Satellite

Nuts and Bolts

What Students Will Do

Build from a shoebox, aluminum foil, paper, rubber bands, glue, tape, and other common materials a structure that will:

1. Protect a cube of ice from melting under a hot lamp or direct sunlight.
2. Protect an egg from fracture when dropped from ten feet.
3. Cost as little as possible to launch into space.

Key Concepts

- The environment of space is extremely hostile, to people and to machines.
- Engineering and building astronomical instruments (telescopes, for example) that are to be launched by rocket and operate in space requires special designs and special materials.
- The building and testing of models of space-bound telescopes can help us figure out the best way to design and build the real thing, before we send it to space or even before we build them.

Materials Needed

Per Class:

- A sensitive scale balance
- Warm sunshine (or a heat lamp if warm sunshine is unavailable)

Per Working Group:

- A shoebox, or other small box
- Any of the following common materials: aluminum foil, colored paper, tape (duct, transparent, masking), glue, rubber bands, scissors, knife, bubble-wrap, cloth, cups, (Styrofoam, paper), toilet paper tubes, paper clips.
- Any other common household/classroom materials that the teacher approves for use
- Zip-Lock bag

- An egg
- An ice cube

Introduction

Description

Space satellite engineers are miracle-makers of a sort. Their task is to design and build machines that can survive the rigorous forces of launch and operate in the hostile environment of outer space without the possibility of being repaired or maintained by humans in any way.

The forces and vibrations of being launched on a rocket are the main reasons that the satellites must be structurally strong. The delicate instruments being transported into space must not be damaged during launch!

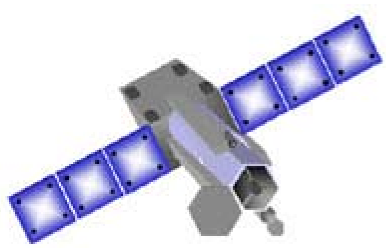
Once in space, the spacecraft must protect its delicate instruments from, among other things, solar radiation in the form of light and high-speed particles ejected by the Sun. Any heat absorbed or produced by the spacecraft must be controlled and disposed of to prevent overheating.

You will design and build a *shoebox satellite*. Given a shoebox and an assortment of materials found commonly around the home or classroom, you will work individually or with partners in your class to construct a contraption that will: (1) Keep a cube of ice from melting for as long as possible when your shoebox satellite is placed in full sunlight, and (2) Protect an egg from being broken when your shoebox satellite is dropped from a height of ten feet over a hard surface.

A third property that your shoebox satellite will compete for is weight. Space flight is very expensive, so you want your shoebox satellite to be as light as possible.

Be creative! Good luck.

Solar-B Connection



During Solar-B's launch into space, if a single bolt comes loose or a fragile mirror cracks, the entire Solar-B mission—millions and millions of dollars and years of time—could fail. Once it has been launched, there is no realistic way to repair even a minor problem.

This is why engineers and scientists must spend years carefully designing, building, and testing the spacecraft and all of its systems. Before Solar-B is launched into space, it will be put through tests of temperature, radiation, and vibration that a human being would quickly fail.

Much of the testing of materials and components will first be done on test models—models so much like the real thing that they could be used as the real thing, if need be.

In the end, the actual spacecraft to be launched will be assembled and put through final testing to make sure no bolts or wires or mirrors or circuit boards come loose during launch.

The role of the engineer is vital in this type of project, as with so many others. An astronaut or astronomer may become famous by flying a spacecraft or making great cosmic discoveries with a satellite observatory—but they would be unable to achieve these things without the machines that spacecraft engineers create.

Design and Build

Overview

You are about to design and build a unique device: a structure that provides both *thermal* and *kinetic* protection, and which is as light as possible. Think about, and discuss with your partner or group, good design procedures that you will employ. When you are finished building the device, it will undergo three tests.

You may want to discuss and/or sketch some of your ideas, prior to building(e.g. come up with a plan/plans). Remember, if you are working with a partner or group, everyone's ideas, input, and assistance are important!

1. A paper cup containing a cube of ice will be loaded into your shoebox satellite's *payload compartment* and the box will be placed in full sunlight. Before heating, the cup and ice together will be weighed and the weight recorded. After heating, when a certain amount of ice has melted to water, any remaining ice will be removed and the cup and water will be weighed together. Comparing the before and after weights will give an indication of how much of the ice melted during the period of heating.
2. An egg will be placed in your payload compartment and your shoebox will be dropped from a height of ten feet over a hard surface, such as concrete. If the egg survives uncracked after your box strikes the ground, the shoebox passes the kinetic design contest.
3. Third, the weight test. The whole shoebox satellite (without egg or ice) will be weighed and the amount of money it would take to launch it into space will be calculated from this weight.

Requirements

Here are the rules. Beyond these, just about anything else goes, at your teacher's discretion. Your teacher, however, has the power to say what else may or may not be done.

- You may use any materials found commonly around the home or classroom (your teacher will decide if a particular thing can be used).
- You must use a shoebox, or something similar, as the main structure.

- Other than changing the payload (ice and cup, egg), you may not alter your shoebox satellite between tests (other than opening and closing the box and the payload compartment to change the payload—whatever you use to hold the box closed for a test must not damage or destroy the box during opening and closing).
- Your shoebox satellite must have a payload compartment—a holder or container of some sort in which the ice and cup (for the thermal test) and the egg (for the kinetic test) will be placed.

Helpful Science Hints

Whether you are working alone or in a group, you may want to think about how you are going to build your satellite to accomplish all of its tasks before you start. Following are a few hints and suggestions that may help.

When the Heat is On

To prevent the ice in the payload from melting in the sunlight, you must prevent heat from the Sun from entering the payload compartment. Since you are not using high-technology materials or active cooling methods (like air conditioning) to accomplish your task, the best you can really hope for is to slow down the buildup of heat in the payload.

The basic ways that heat travels are by *radiation*, *conduction*, and *convection*.

Radiation: Heat energy travels by radiation in the form of light.

The sunlight shining on your box carries energy, which strikes the box and heats up the materials in it. Once the box is heated up, it begins to emit its own light in the form of infrared radiation. The infrared light can shine from one place to another, heating up parts of the box that are not otherwise in direct sunlight.

Conduction: Heat energy travels by conduction in the form of moving atoms striking other nearby atoms and causing them to move as well.

Atoms and molecules in an object move around and vibrate faster and faster when heated—in fact, heat is that motion; heat is energy carried in the motion of matter. In solid objects, heat energy will spread out as the moving atoms strike neighboring atoms and set them, too, into motion.

Convection: Heat travels by convection when a region of fluid is heated and moves upward.

When a fluid (gas or liquid) is heated, it expands. As a result, it becomes less dense than the unheated fluid around it. As a result of this, the warmer, lighter fluid rises upward, carrying the heat it contains with it.

Fight the Impulse

When it comes to cars crashing into trees, falling objects striking the ground, or spacecraft being hurled into space on rockets, there is one thing common to them all: they are all experiencing changes in velocity, or speed, some more rapidly than others.

The word *impulse* is used to describe an impact. It is the force of the impact multiplied by the amount of time the force is exerted. This product, impulse = force x time, is the total change of momentum experienced by the object.

In general, there are two types of impulse: 1) Hard and fast, and 2) Soft and slow. Hard and fast is usually not the way you would like to experience a change in velocity. That's when you run into a brick wall at full speed, going from fast to stopped in a fraction of a second. The great amount of force you experience over the short amount of time can result in broken bones, or worse.

Soft and slow is the way to go. If the wall you run into is padded, like a mattress, you will enjoy the result more than if you run into bricks. You are not stopped the instant you hit the mattress, but rather the mattress bends and gives, pushing back against you with a weaker force, but over a longer period of time.

To give your egg payload the best chance for survival, you need to think about how to give it the soft and slow type of impulse. Anything you can do to increase the amount of time that the egg is being slowed down by the force of impact with the ground will increase its chances of not being cracked.

Test

Thermal Test

With Sunlight: If sunlight is used for the thermal test, the teacher should locate a good place outside, in the sunlight, where the shoebox satellites can be placed. The surface must be large enough to accommodate all of the shoeboxes, and must be a uniform surface like cement, a lawn, blacktop, etc. This is to make the contest fair, since some surfaces may be hotter than others (for example, asphalt as opposed to grass) and affect the test.

With a Hot Lamp: The best way to perform the thermal test is to place the shoebox satellites in full sunlight. However, if the weather is cool or cold even in full sunlight, the ice may not melt quickly enough, or at all. In cold weather, the teacher may decide to use a bright, hot lamp instead of sunlight. In this case, each shoebox satellite should be placed under the lamp at the same distance (preferably very close to give it the greatest amount of heat exposure).

- All students must be ready to go at the same time.
- The teacher will distribute a cube of ice to each student. This will be done as quickly as possible.
- As soon as you have the cube of ice, place it in a Zip-Lock bag, seal the bag, and weigh the two (bag and ice) together. Record this weight in the table below.
- On your mark, get set, GO! Install the bagged ice into your shoebox satellite's payload compartment.
- The whole class will move their shoebox satellites outside into the sunlight and place them in the pre-chosen test area.
- The shoebox satellites must be left alone, in full sunlight, for 20 full minutes. (Note: the teacher may change this amount of time depending on prevailing weather conditions.)
- At the end of the test period, all of the shoebox satellites should be quickly and carefully brought out of the sunlight and opened.
- Immediately pour out any liquid water from the Zip-Lock bag, leaving any unmelted ice in the bag.
- Weigh the bag and ice together and record the number in the table below.

- Do the calculation below. If you are doing the activity as a competition among students, the shoebox satellite with the smallest difference in weight (the smallest amount of melted ice) wins the thermal test! (If you choose to have the students compete against a predetermined set of criteria, then all students who meet the criteria “win.”)

Weight Before: Bag + Ice	Weight After: Bag + Ice	Difference (Weight Before) – (Weight After)

Kinetic Test

The exact way to conduct the kinetic test will be decided upon by the teacher. Dropping each shoebox satellite from a certain height over a hard surface is one method. Creating a giant slingshot from a bucket and long pieces of rubber surgical tubing and launching the shoeboxes upward is another. Whatever method is used, <u>the same method should be used for testing all shoebox satellites</u>.

- Each participant will be given one egg.
- Place the egg in the payload compartment.
- By the method chosen, drop or launch the shoebox satellite and allow it to land on the ground.
- Open each shoebox satellite.
- Using the Damage Assessment Table below, the teacher or students will rate the amount of damage suffered by each egg and circle the result on the table.

Damage Assessment Table	
No damage to egg	**0**
At least 1 crack in shell	**1**
At least 1 crack with small leakage of egg white	**2**
Shell broken with much egg white lost	**3**
Shell broken, major egg white loss, yoke broken	**4**

Cost Test

Designing, building, and testing a satellite is only the ground work. A satellite must actually be launched into space to begin its life of useful operation. But placing objects into space comes at a price—a big one. To see how much it would cost for NASA's space shuttle to place your shoebox satellite into orbit, do the following.

- Weigh your shoebox satellite, obtaining a result in grams.
- Multiply the grams by 100 and record the result below.
- The result is how many dollars it would cost to carry your shoebox satellite into a low Earth orbit.

Weight (grams)	Weight x $100/gram	Cost to Launch

Note: The value of $100 per gram is a rough figure, but not unrealistic.

Space exploration is not cheap.

Lessons Learned / Questions / New Ideas

After the thermal and kinetic testing is done, each group can discuss/write about their satellite, what they expected to happen, what in fact happened, lessons learned, questions, what worked (and why they think so) and what did not work (and why they think so), and what change or changes they would make to their design and why. Then, each group can make a brief presentation to the whole class, and students can ask one another questions/make comments. This discussion could center around some of the following questions.

Thermal

1. How many thermal phenomena (for example, convection, conduction, reflection, absorption) did the shoebox satellite exploit?
2. In how many ways did the design of the shoebox satellite prevent heat from reaching the payload?
3. In how many ways did the design of the shoebox satellite remove heat from the area of the payload?

Kinetic

1. Was the shoebox satellite designed in any way to slow down the falling speed of the box?
2. Was the payload isolated from the rest of the shoebox so that the payload may have experienced a softer and slower impulse than the box?
3. What else in the shoebox satellite's design may have softened the impulse of landing?

Cost

1. List any reasons you see for the shoebox satellite being as light as it is.
2. What do you think could have been done to make the shoebox satellite even lighter?

Design and Materials Tips

Tips For Applying Thermal Science to Your Design:

- Aluminum foil is a great reflector of sunlight. Any sunlight that you can reflect away from your box is energy that cannot cause the box to heat up. A white object is bright and white because it reflects much of the light striking it. Aluminum foil is even better. As you think about your design plan, where and how might you use aluminum foil?

- Metal (including aluminum foil) is a conductor of heat: any heat contacting the metal will spread quickly through it. If you want to prevent heat from conducting through a piece of your shoebox satellite, use material that is a good insulator—that is, something that does not conduct heat well. Styrofoam is an excellent thermal insulator. Paper or cardboard is okay, but not quite as good. As you think about your design plan, where and how might you use styrofoam?
- Vent holes cut in the right places can aid convection of air. If the air inside your shoebox does start to heat up, you can remove some of that heat by allowing the air to convect out of and away from the box. Vent holes cut in the top of your box will allow air to rise up and out, while vent holes cut near the bottom will allow cooler outside air to be sucked into the box to take the place of the air leaving through the top. Note: If you cut holes in the top, you may want to think about what will happen if sunlight is allowed to shine through those holes directly into the box—and perhaps think of a way to prevent this….

Tips For Applying Kinetic Science to Your Design:

- Rubber bands make a good suspension system. Rubber bands stretch, and can be used as shock absorbers. If you can isolate your payload compartment from the rest of the shoebox, and figure out how best to give the payload adequate “stretching room,” all the better. As you consider your design plan, what are some ways you might use rubberbands?
- Duct tape is a strong and durable bonding device. For holding things together, duct tape is king. It also sticks to itself well. In what ways might duct tape be useful in your design?
- Bubble-wrap and other forms of plastic sheeting are also useful for protecting objects from damage. (Also, bubble-wrap is a pretty good thermal insulator.) Where and how might you use bubble wrap?
- If you think the egg in your payload compartment will fare better if the shoebox satellite lands on a particular side, then you might think about how to force the shoebox to land on the desired side. Tail fins, such as you may have seen on a rocket, work pretty well for this, if you use them right.

Solar-B:
Touch the Sun

Alignment with
Education Standards

Education Standards Alignment Matrix

Education Standards **Alignment Matrix**	sunspotter	sundial	pinhole cam	spectroscope	colorgraphs	polarimeter	shoebox sat	general
National Science Education Standards Grades 5 - 8								
1. Science As Inquiry								
Content Standard A: As a result of activities in grades 5 – 8, all students should develop abilities necessary to do scientific inquiry and understandings about scientific inquiry.								
Abilities Necessary To Do Scientific Inquiry:								
Identify questions that can be answered through scientific investigations.	✓	✓	✓		✓		✓	
Design and conduct a scientific investigation.			✓		✓		✓	
Use appropriate tools and techniques to gather, analyze, and interpret data.	✓	✓	✓	✓	✓	✓	✓	
Develop descriptions, explanations, predictions, and models using evidence.	✓	✓	✓	✓	✓		✓	
Think critically and logically to make the relationships between evidence and explanations.	✓	✓	✓	✓	✓	✓	✓	
2. Physical Science								
Content Standard B: As a result of their activities in grades 5 – 8, all students should develop an understanding of:								
Motions and Forces								
* The motion of an object can be described by its position, direction of motion, and speed. That motion can be measured and represented on a graph.	✓	✓						
Transfer of Energy								
* Light interacts with matter by transmission (including refraction), absorption, or scattering				✓	✓			

Education Standards **Alignment Matrix**	sunspotter	sundial	pinhole cam	spectroscope	colorgraphs	polarimeter	shoebox sat	general
(including reflection).								
* The sun is a major source of energy for changes on the earth's surface. The sun loses energy by emitting light. A tiny fraction of that light reaches the earth, transferring energy from the sun to the earth. The sun's energy arrives as light with a range of wavelengths, consisting of visible light, infrared, and ultraviolet radiation.				✓	✓	✓		✓
3. Earth and Space Science								
Content Standard D: As a result of their activities in grades 5 – 8, all students should develop an understanding of : a. structure of the earth system b. earth's history c. earth in the solar system								
c. Earth in the Solar System:								
* The sun is the major source of energy for phenomena on the earth's surface, such as growth of plants, winds, ocean currents, and the water cycle. Seasons result from variations in the amount of the sun's energy hitting the surface, due to the tilt of the earth's rotation on its axis and the length of the day.								✓
4. Science and Technology								
Content Standard E: As a result of activities in grades 5 – 8, all students should develop: a. abilities of technological design b. understandings about science and technology								
a. Abilities of Technological Design:								
* identify appropriate problems for technological design			✓				✓	
* design a solution or product							✓	
* implement a proposed design							✓	
* evaluate completed technological designs or products							✓	
* communicate the process of technological design							✓	

Education Standards **Alignment Matrix**	sunspotter	sundial	pinhole cam	spectroscope	colorgraphs	polarimeter	shoebox sat	general
b. Understandings About Science and Technology:								
* Scientific inquiry and technological design have similarities and differences. Scientists propose explanations for questions about the natural world, and engineers propose solutions relating to human problems, needs, and aspirations. Technological solutions are temporary; technologies exist within nature and so they cannot contravene physical or biological principles; technological solutions have side effects; and technologies cost, carry risks, and provide benefits.								✓
* Science and technology are reciprocal. Science helps drive technology, as it addresses questions that demand more sophisticated instruments and provides principles for better instrumentation and technique. Technology is essential to science, because it provides instruments and techniques that enable observations of objects and phenomena that are otherwise unobservable due to factors such as quantity, distance, location, size, and speed. Technology also provides tools for investigations, inquiry, and analysis.								✓
* Perfectly designed solutions do not exist. All technological solutions have tradeoffs, such as safety, cost, efficiency, and appearance. Engineers often build in back-up systems to provide safety. Risk is part of living in a highly technological world. Reducing risk often results in new technology.								✓
* Technological designs have constraints. Some constraints are unavoidable, for example, properties of materials, or effects of weather and friction; other constrains limit choices in the design, for example, environmental protection, human safety, and aesthetics.								✓
5. History and Nature of Science								
Content Standard G: As a result of activities in grades 5 – 8, all students should develop understanding of: a. science as a human endeavor b. nature of science **c.** history of science								

Education Standards **Alignment Matrix**	sunspotter	sundial	pinhole cam	spectroscope	colorgraphs	polarimeter	shoebox sat	general
b. Nature of Science:								
* Scientists formulate and test their explanations of nature using observation, experiments, and theoretical and mathematical models. Although all scientific ideas are tentative and subject to change and improvement in principle, for most major ideas in science, there is much experimental and observational confirmation. Those ideas are not likely to change greatly in the future. Scientists do and have changed their ideas about nature when they encounter new experimental evidence that does not match their existing explanations.								✓
National Science Education Standards **Grades 9 - 12**								
1. Science as Inquiry								
Content Standard A: As a result of activities in grades 9 – 12, all students should develop: a. abilities necessary to do scientific inquiry b. understandings about scientific inquiry								
a. Abilities necessary to do Scientific Inquiry								
* Identify questions and concepts that guide scientific investigations	✓	✓	✓	✓	✓	✓	✓	
* Design and conduct scientific investigations	✓	✓	✓				✓	
* Use technology and mathematics to improve investigations and communications	✓	✓	✓	✓	✓	✓	✓	
* Formulate and revise scientific explanations and models using logic and evidence	✓	✓	✓	✓	✓	✓	✓	
b. Understandings About Scientific Inquiry								
* Scientists conduct investigations for a wide variety of reasons. For example, they may wish to discover new aspects of the natural world, explain recently observed phenomena, or test the conclusions of prior investigations or the predictions of current theories.								✓
* Scientists rely on technology to enhance the gathering and manipulation of data. New techniques and tools provide new evidence to								✓

Education Standards **Alignment Matrix**	sunspotter	sundial	pinhole cam	spectroscope	colorgraphs	polarimeter	shoebox sat	general
guide inquiry and new methods to gather data, thereby contributing to the advance of science. The accuracy and precision of the data, and therefore the quality of the exploration, depends on the technology used								
* Mathematics is essential in scientific inquiry. Mathematical tools and models guide and improve the posing of questions, gathering data, constructing explanations and communicating results	✓	✓	✓	✓	✓	✓	✓	
4. Science and Technology								
Content Standard E: As a result of activities in grades 9 – 12, all students should develop: a. Abilities of technological design b. * Understandings about science and technology								
a. Abilities of Technological Design								
* Identify a problem or design an opportunity			✓				✓	
* Propose designs and choose between alternative solutions			✓				✓	
* Implement a proposed solution							✓	
* Evaluate the solution and its consequences							✓	
* Communicate the problem, process, and solution							✓	
b. Understandings About Science and Technology								
* Many scientific investigations require the contributions of individuals from different disciplines, including engineering.							✓	
* Science often advances with the introduction of new technologies. Solving technological problems often results in new scientific knowledge. New technologies often extend the current levels of scientific understandings and introduce new areas of research.							✓	
* Creativity, imagination, and a good knowledge base are all required in the work of science and engineering.							✓	

Education Standards **Alignment Matrix**	sunspotter	sundial	pinhole cam	spectroscope	colorgraphs	polarimeter	shoebox sat	general
* Science and technology are pursued for different purposes. Scientific inquiry is driven by the desire to understand the natural world, and technological design is driven by the need to meet human needs and solve human problems. Technology, by its nature, has a more direct effect on society than science because its purpose is to solve human problems, help humans adapt, and fulfill human aspirations. Technological solutions may create new problems. Science by its nature, answers questions that may or may not directly influence humans. Sometimes scientific advances challenge people's beliefs and practical explanations concerning various aspects of the world.								✓
5. History and Nature of Science								
Content Standard G: As a result of activities in grades 9 – 12, all students should develop understanding of: a. Science as a human endeavor b. Nature of scientific knowledge c. Historical perspectives								
b. Nature of Scientific Knowledge								
* Science distinguishes itself from other ways of knowing and from other bodies of knowledge through the use of empirical standards, logical arguments, and skepticism, as scientists strive for the best possible explanations about the natural world.	✓	✓	✓	✓	✓	✓	✓	✓
* Scientific explanations must meet certain criteria. First and foremost, they must be consistent with experimental and observational evidence about nature, and must make accurate predictions, when appropriate, about systems being studied. They should also be logical, respect the rules of evidence, be open to criticism, report methods and procedures, and make knowledge public.	✓	✓	✓	✓	✓	✓	✓	✓
* Because all scientific ideas depend on experimental and observational confirmation, all scientific knowledge is, in principle, subject to change as new evidence becomes available.								✓

Education Standards **Alignment Matrix**	sunspotter	sundial	pinhole cam	spectroscope	colorgraphs	polarimeter	shoebox sat	general
National Mathematics Education Standards Grades 6 – 8								
Instructional Programs in Grades 6 – 8 should enable all students to do the following:								
Number and Operations Standard								
Understand numbers, ways of representing numbers, relationships among numbers, and number systems work flexibly with fractions, decimals, and percents to solve problems	✓	✓	✓	✓	✓	✓	✓	✓
Understand meanings of operations and how they relate to one another understand the meaning and effects of arithmetic operations with fractions, decimals, and integers		✓	✓	✓	✓	✓	✓	✓
Compute fluently and make reasonable estimates select appropriate methods and tools for computing with fractions and decimals from among mental computation, estimation, calculators or computers, and paper and pencil, depending on the situation, and apply the selected methods		✓	✓	✓	✓	✓	✓	✓
Algebra Standard								
Understand patterns, relations, and functions represent, analyze, and generalize a variety of patterns with tables, graphs, words, and, when possible, symbolic rules		✓		✓	✓	✓		
Represent and analyze mathematical situations and structures using algebraic symbols, develop an initial conceptual understanding of different uses of variables			✓	✓	✓	✓		
Use mathematical models to represent and understand quantitative relationships, model and solve contextualized problems using various representations, such as graphs, tables, and equations	✓	✓	✓	✓	✓	✓		
Analyze change in various contexts, use graphs to analyze the nature of changes in quantities in linear relationships	✓	✓	✓	✓	✓	✓		✓

Education Standards **Alignment Matrix**	sunspotter	sundial	pinhole cam	spectroscope	colorgraphs	polarimeter	shoebox sat	general
Measurement Standard								
Understand measurable attributes of objects and the units, systems, and processes of measurement								
Apply appropriate techniques, tools, and formulas to determine measurements	✓	✓	✓	✓	✓	✓	✓	✓
Data Analysis Standard								
Formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them	✓	✓	✓	✓	✓	✓	✓	✓
Select and use appropriate statistical methods to analyze data	✓	✓	✓	✓	✓	✓		
Develop and evaluate inferences and predictions that are based on data	✓	✓	✓	✓	✓	✓		
Problem Solving Standard								
Build new mathematical knowledge through problem solving			✓	✓	✓	✓	✓	✓
Solve problems that arise in mathematics and in other contexts		✓	✓	✓	✓	✓	✓	✓
Monitor and reflect on the process of mathematical problem solving		✓	✓	✓	✓	✓	✓	✓
Communication Standard for Grades 6–8								
Organize and consolidate their mathematical thinking through communication								✓
Analyze and evaluate the mathematical thinking and strategies of others		✓	✓	✓	✓	✓	✓	✓
Use the language of mathematics to express mathematical ideas precisely		✓	✓	✓	✓	✓	✓	✓
Connections Standard								
Recognize and apply mathematics in contexts outside of mathematics	✓	✓	✓	✓	✓	✓	✓	✓
Representations Standard								
Create and use representations to organize, record, and communicate mathematical ideas	✓	✓	✓	✓	✓	✓	✓	✓
Use representations to model and interpret physical, social, and mathematical phenomena	✓	✓	✓	✓	✓	✓	✓	✓
Select, apply, and translate among mathematical representations to solve problems		✓	✓	✓	✓	✓		✓
National Mathematics Education Standards For Grades 9 – 12								

Education Standards

Alignment Matrix

	sunspotter	sundial	pinhole cam	spectroscope	colorgraphs	polarimeter	shoebox sat	general
Instructional programs in Grades 9 – 12 should enable all students to:								
Numbers and Operations Standard								
Understand numbers, ways of representing numbers, relationships among numbers, and number systems		✓	✓	✓	✓	✓		✓
Algebra and Functions Standard								
Understand patterns, relations, and functions		✓		✓	✓			
Use mathematical models to represent and understand quantitative relationships		✓	✓	✓	✓	✓	✓	
Analyze change in various contexts	✓	✓	✓	✓	✓	✓	✓	✓
Geometry Standard								
Use trigonometric relationships to determine lengths and angle measures		✓	✓					
Specify locations and describe spatial relationships using coordinate geometry and other representational systems		✓						
Measurement Standard								
Understand measurable attributes of objects and the units, systems, and processes of measurement	✓	✓	✓	✓	✓	✓	✓	✓
Apply appropriate techniques, tools, and formulas to determine measurements	✓	✓	✓	✓	✓	✓	✓	✓
Data Analysis and Probability Standard								
Formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them		✓	✓	✓	✓	✓	✓	
Select and use appropriate statistical methods to analyze data		✓		✓	✓			
Develop and evaluate inferences and predictions that are based on data	✓	✓	✓	✓	✓	✓	✓	✓
Problem Solving Standard								
Solve problems that arise in mathematics and in other contexts		✓	✓	✓	✓	✓	✓	✓
Apply and adapt a variety of appropriate strategies to solve problems		✓	✓	✓	✓	✓	✓	✓
Mathematical Communication Standard								
Communicate their mathematical thinking coherently and clearly to peers, teachers, and others		✓	✓	✓	✓	✓	✓	✓

Education Standards **Alignment Matrix**	sunspotter	sundial	pinhole cam	spectroscope	colorgraphs	polarimeter	shoebox sat	general
Analyze and evaluate the mathematical thinking and strategies of others		✓	✓	✓	✓	✓	✓	✓
Mathematical Connections Standard								
Recognize and apply mathematics in contexts outside of mathematics		✓	✓	✓	✓	✓	✓	✓
Representation Standard								
Create and use representations to organize, record, and communicate mathematical ideas	✓	✓	✓	✓	✓	✓	✓	✓
Select, apply, and translate among mathematical representations to solve problems		✓	✓	✓	✓	✓	✓	✓
Use representations to model and interpret physical, social, and mathematical phenomena		✓	✓	✓	✓	✓	✓	✓
California Science Standards Alignment **Grade 8—Focus on Physical Science**								
Motion								
1. The velocity of an object is the rate of change of its position. As a basis for understanding this concept, students know:								
c. how to solve problems involving distance, time, and average speed.	✓	✓						
f. how to interpret graphs of position versus time for motion in a single direction	✓	✓						
Earth in the Solar System (Earth Science)								
4. The structure and composition of the universe can be learned from the study of stars and galaxies, and their evolution. As a basis for understanding this concept, students know:								
b. the sun is one of many stars in	✓		✓					

Education Standards **Alignment Matrix**	sunspotter	sundial	pinhole cam	spectroscope	colorgraphs	polarimeter	shoebox sat	general
our own Milky Way galaxy. Stars may differ in size, temperature, and color.								
Investigation and Experimentation								
9. Scientific progress is made by asking meaningful questions and conducting careful investigations. As a basis for understanding this concept, and to address the content in the other three strands, students should develop their own questions and perform investigations. Students will:								
a. plan and conduct a scientific investigation to test a hypothesis.	✓	✓		✓	✓		✓	
b. evaluate the accuracy and reproducibility of data.	✓	✓	✓	✓	✓	✓	✓	
c. distinguish between variable and controlled parameters in a test.		✓	✓	✓	✓	✓	✓	
e. construct appropriate graphs from data and develop quantitative statements about the relationships between variables.		✓		✓	✓	✓		
f. apply simple mathematical relationships to determine one quantity given the other two.		✓	✓		✓		✓	
g. distinguish between linear and nonlinear relationships on a graph of data.		✓						
California Science Standards Alignment								

Education Standards **Alignment Matrix**	sunspotter	sundial	pinhole cam	spectroscope	colorgraphs	polarimeter	shoebox sat	general
Grades 9 - 12								
Waves								
4.Waves have characteristic properties that do not depend on the type of wave. As a basis for understanding this concept, students know:								
a. waves carry energy from one place to another				✓	✓	✓	✓	
e. radio waves, light, and x-rays are different wavelength bands in the spectrum of electromagnetic waves whose speed in a vacuum is approximately 3 x 10 m/s (186,000 miles/second).				✓	✓			
f. how to identify the characteristic properties of waves: interference (beats), diffraction, refraction, Doppler effect, and polarization.				✓	✓	✓		
Electric and Magnetic Phenomena								
Electric and magnetic phenomena are related and have many practical applications. As a basis for understanding this concept, students know:								
f. magnetic materials and electric currents (moving electric charges) are sources of magnetic fields and are subject to forces arising from the magnetic fields of other sources.	✓					✓		

Education Standards **Alignment Matrix**	sunspotter	sundial	pinhole cam	spectroscope	colorgraphs	polarimeter	shoebox sat	general
CHEMISTRY								
Atomic and Molecular Structure								
1. The periodic table displays the elements in increasing atomic number and shows how periodicity of the physical and chemical properties of the elements relates to atomic structure. As a basis for understanding these concepts, students know:								
j* spectral lines are a result of transitions of electrons between energy levels. Their frequency is related to the energy spacing between levels using Planck's relationship (E=hv)				✓				
EARTH SCIENCES								
Earth's Place in the Universe								
1. Astronomy and planetary exploration reveal the solar system's structure, scale, and change over time.	✓	✓	✓					
2. Earth-based and space-based astronomy reveal the structure, scale, and changes in stars, galaxies, and the universe over time. As a basis for understanding this concept, students know:								
d. that stars differ in their life cycles and that visual, radio, and x-ray telescopes may be used to collect data that reveal those								✓

Education Standards **Alignment Matrix**	sunspotter	sundial	pinhole cam	spectroscope	colorgraphs	polarimeter	shoebox sat	general
differences.								
INVESTIGATION AND EXPERIMENTATION								
1. Scientific progress is made by asking meaningful questions and conducting careful investigations. As a basis for understanding this concept and addressing the content in the other four strands, students should develop their own questions and perform investigations. Students will:								
b. Identify and communicate sources of unavoidable experimental error.	✓	✓	✓				✓	
c. Identify possible reasons for inconsistent results, such as sources of error or uncontrolled conditions.								✓
d. Formulate explanations by using logic and evidence.								✓
g. Recognize the usefulness and limitations of models and theories as scientific representations of reality.							✓	
i. Analyze the locations, sequences, or time intervals that are characteristic of natural phenomena (e.g., relative ages of rocks, locations of planets over time, and succession of species in an ecosystem).	✓	✓	✓	✓	✓	✓		
j. Recognize the issues of		✓		✓	✓	✓	✓	✓

Education Standards **Alignment Matrix**	sunspotter	sundial	pinhole cam	spectroscope	colorgraphs	polarimeter	shoebox sat	general
statistical variability and the need for controlled tests.								
l. Analyze situations and solve problems that require combining and applying concepts from more than one area of science.							✓	
n. Know that when an observation does not agree with an accepted scientific theory, the observation is sometimes mistaken or fraudulent and that the theory is sometimes wrong.								✓